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## SOUNDINGS TAKEN DURING THE DISCOVERY INVESTIGATIONS, 1932–39

*by*

H. F. P. Herdman, M.Sc.

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By

H. F. P. HERDMAN, M.Sc.

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# SOUNDINGS TAKEN DURING THE DISCOVERY INVESTIGATIONS, 1932–39

By H. F. P. Herdman, M.Sc.

(Text-figs. 1–19, Plates XXIII–XXXI)

## INTRODUCTION

THE oceanic soundings taken by the R.R.S. 'Discovery', 'Discovery II' and 'William Scoresby' from 1926 to 1932 have been dealt with in a previous report (Herdman, 1932). Most of the soundings in that period were in the West Antarctic region, and the report included descriptions of the sounding equipment then in use, an account of the Scotia Arc and its significance, comments on the bottom topography of the Scotia Sea and neighbouring regions, and bathymetric charts of the Scotia Sea, the vicinity of South Georgia, and the Bransfield Strait and adjacent waters. Between 1932 and 1939 many thousands of additional echo soundings (far more than in the period before 1932) were taken by the 'Discovery II', together with a small number of Lucas soundings taken on station by the 'William Scoresby' and by the 'Discovery II' when her deep-water echo-sounding set was temporarily out of order. These new soundings are spread over nearly all parts of the Southern Ocean (see Text-fig. 18, p. 89); they greatly amplify the previous soundings in the West Antarctic region; and they throw much new light on some areas of special interest. Owing to the dispersal of the Discovery Committee's staff during the years of war this very large accumulation of data could not be analysed until now.

Although many unpublished oceanic soundings are available, the time has hardly come for a new bathymetric chart of the Southern Ocean. Nevertheless, the data justify a review of the bottom topography associated with the Scotia Arc, an account of soundings taken during various hydrographic surveys, and an account of certain localities in which the bathymetric features are of some oceanographical or geological significance. When deep-sea echo soundings are undertaken on a large scale, especially in regions of much bad weather, many practical difficulties arise which have not been adequately dealt with in previous publications. In the following pages, therefore, and in Appendix I considerable attention is given also to technique; and the interpretation of individual soundings and continuous records is also discussed.

The present report is based on the Discovery Committee's data, but in the preparation of the contour charts soundings from all available sources have been used, especially in the Ross Sea area, where a considerable number of echo soundings were taken between the years 1933 and 1935 by the second Byrd Antarctic Expedition. In the Scotia Sea area and in the Bransfield Strait we have used the full results of the 'Meteor' sounding programme, which agree well with our own observations. With these exceptions the number of soundings from other sources in the areas concerned is almost negligible and in most instances adds little or nothing to the information obtained from our own observations. In fact, our intensive sounding programme has shown that either the position or depth of some of the earlier soundings from other sources is quite unreliable.

Soundings taken by the 'Discovery II' may be roughly classified in three main groups: (*a*) Routine oceanic soundings, normally taken every hour when on passage, at every scientific station and when steaming between stations, (*b*) Soundings taken during hydrographical survey work, and (*c*) Special soundings taken on the occasions when a submarine ridge, bank or other interesting feature of the ocean floor was being crossed. The routine soundings (*a*) were usually obtained under way at normal

cruising speed, i.e. 9 knots. If, however, conditions were unsuitable for this and it was important that the line of soundings should be as complete as possible then the ship was either manœuvred with regard to sea and wind or hove-to for a few minutes until the sounding had been completed. For (*b*) soundings were taken as often as the scale of the survey required, and in later years a continuous record from the recording machines was our aim. At times this entailed twelve to fourteen hours continuous running of the automatic recorders, which were fitted in recent years; but with the exception of minor breakdowns these machines generally stood up well to the work. Special soundings (*c*) were usually taken whenever any known ridge or bank was being crossed or when the hourly sounding showed any marked change in depth. In the earlier years when only 'listening' sets were fitted the spacing of the soundings was decided according to the condition of sea and weather, or to the slope of the bottom. In recent years it was the practice to try for a continuous record over the area concerned.

In this report prominence has been given mainly to oceanic and special soundings, since the detailed soundings taken on hydrographical surveys have only a limited value so far as hydrological conditions in the oceans are concerned. Nor are they of much value in the determination of major geological features. The soundings taken during the survey of the South Orkney Islands have already been shown on the chart published with a report on those islands by Marr (1935), but the intensive soundings taken in the South Shetland Islands between 1934 and 1937 have not, as yet, been examined by us in detail.

The positions of the soundings taken by the 'Discovery II' and discussed in this report were determined as follows: From 1932 to 1935, by Lt. A. L. Nelson, R.N.R.; from October 1935 until June 1937 by Lt. R. Walker, R.N.R.; and for the period of September 1937 to May 1939 by Lts. L. C. Hill, O.B.E., R.N.R. and A. F. Macfie, R.N.R. The careful work and willing co-operation of these officers has done much to assist me in the preparation of this report. From 1932 until early in 1936 all the soundings were plotted by these officers on large-scale charts, but from 1936, in order to meet the wishes of the Hydrographer of the Navy, lists of soundings and their positions were prepared at regular intervals, and plotting was thus discontinued except during survey work.

This report has been considered in manuscript by Mr J. M. Wordie, C.B.E., M.A. and the Hydrographer of the Navy (Rear-Admiral A. G. N. Wyatt, C.B., R.N.); to them I am grateful for advice and valuable suggestions. It has also been read by the Superintending Scientist of H.M. Underwater Detection Establishment (Mr J. Anderson, O.B.E.) and several members of his staff. To one of them, Mr J. H. Hayes, a pioneer of the earlier experimental work in deep-sea echo sounding, I am much indebted for very helpful criticisms and advice on certain technical points.

In the preparation of the figures and contour charts I have received considerable assistance from the Hydrographic Department of the Admiralty, especially from the Superintendent of Charts, Captain E. H. B. Baker, D.S.O., R.N. Through his courtesy I have been able at any time to consult our original survey charts and plans, now in the possession of the Hydrographic Department.

Finally, I should like to express my gratitude to Dr N. A. Mackintosh for the help he has so freely given me at all stages in the preparation of this report. His practical experience of the sounding routine in the 'Discovery II' has materially assisted me in the presentation of what I hope is a balanced account of our sounding work.

## SOUNDING EQUIPMENT

When the previous report was written the 'Discovery II' was fitted with Lucas and Kelvin machines for wire soundings, and with deep and shallow echo-sounding sets of the 'listening' pattern. A full description of these instruments and their positions in the ship has been given already in the earlier

sounding report, and particulars appear also in the report on the R.R.S. 'Discovery II' by Ardley and Mackintosh (1936, pp. 102–4). Though little used in recent years, the Lucas and Kelvin sounding machines remained as part of our standard sounding equipment; some amplification, however, of the description of the echo-sounding sets given in the latter report is required, and details will be found here in Appendix I (p. 95).

## DEEP-WATER ECHO-SOUNDING SET

During the six years in which the 'Acadia' type recorder was used with the deep-water echo-sounding set, little electrical or mechanical trouble was experienced with the recorder mechanism, and records covering some 900 hours of running were made and stored. Very approximately this represents a continuous survey of about 6000 miles of the ocean floor, from which a virtually permanent record is available, but the recorder was used also on numerous occasions for short periods up to 20 minutes from which the record itself was not kept, but from which soundings had been noted. The positions of the great majority of these oceanic records are shown in Text-figs. 1 and 2. A large proportion of the stored records were taken during the running surveys of the South Shetland and South Orkney Islands and the tracks of the ship at these times are shown in detail in Text-figs. 3 and 4 together with the tracks of records taken at Tristan da Cunha, South Georgia, the Balleny group and other islands. A considerable number of continuous records were also obtained in open water and across such features as the Burdwood Bank, the Kerguelen-Gaussberg Ridge and a newly discovered bank in 42° S, on the meridian of Greenwich. The depths recorded varied from 25 fm. (46 m.), the average minimum depth at which soundings could be read,[1] to just over 3000 fm. (5486 m.), which was the greatest depth at which we obtained a clear record. A complete list of all records, with their positions, is given in Appendix II (p. 98) to this report. In Appendix I (p. 95), which deals mainly with certain technical difficulties met with in the operation of the echo-sounding sets, reference will also be found to the effect of extraneous noises on the echo marking on these records. Water noises and the passage of the ship through pack-ice can completely obscure the echo marking, but on the whole our records are very free from interference from these sources.

## SHALLOW-WATER ECHO-SOUNDING SET

The sonic pattern 'listening' set, described in our previous reports, was in use until 1935, and was then replaced by an Admiralty System Magnetostriction set with a Mark XIID recorder. This is a supersonic set (emitting soundwaves beyond the audible range) and it was manufactured and fitted by Messrs Henry Hughes & Son Ltd. The principle of the British Admiralty system of supersonic echo sounding with magnetostriction transmission is well known and has already been described in considerable detail in the *Hydrographic Review* (1934, 1936 and 1937). It is sufficient, therefore, to say that the range of this new set was 0–130 fm. (0–238 m.) on the slow or normal speed, with one phase addition of 100 fm., making the total range 0–230 fm. (0–421 m.). On the fast speed soundings were obtained in feet, with a corresponding range of 0–230 ft. (0–70 m.).

Few difficulties arose in the operation of this set, but there are certain technical points on which fuller information appears desirable. This information, together with the details of the arrangement of the transmitter and receiver in the hull of the 'Discovery II', will be found in Appendix I (p. 95).

[1] At depths less than 25 fm. (46 m.) the echo marking on the 'Acadia' record tended to merge with the transmission band. Reduction of the sensitivity of the receiving circuit allowed the echo marking to be clearly distinguishable at lesser depths but, to allow for greater accuracy in the shallower soundings, it was our normal practice to use the shallow machines for soundings less than 50 fm. (91 m.).

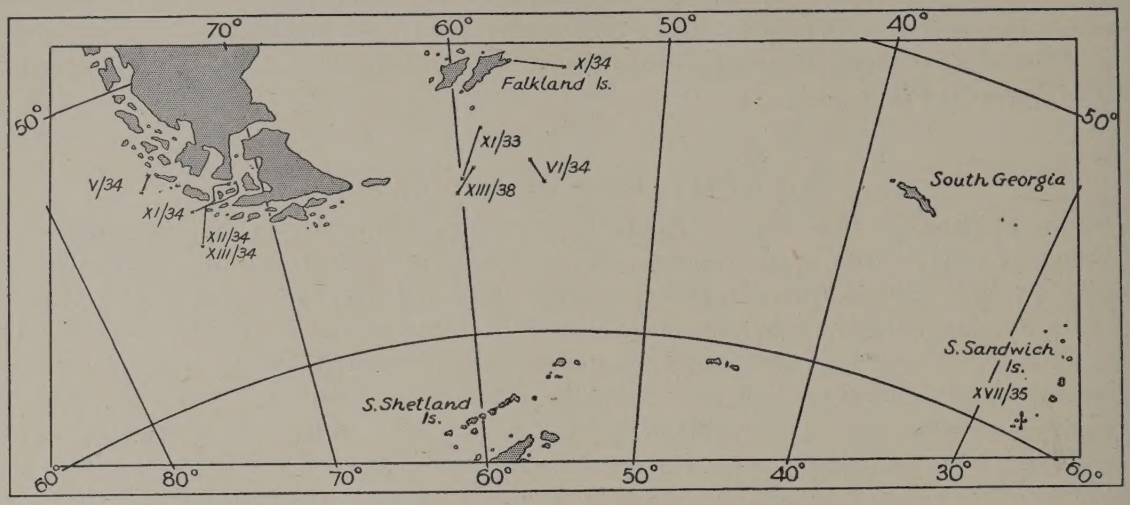


Fig. 1 (*a*).

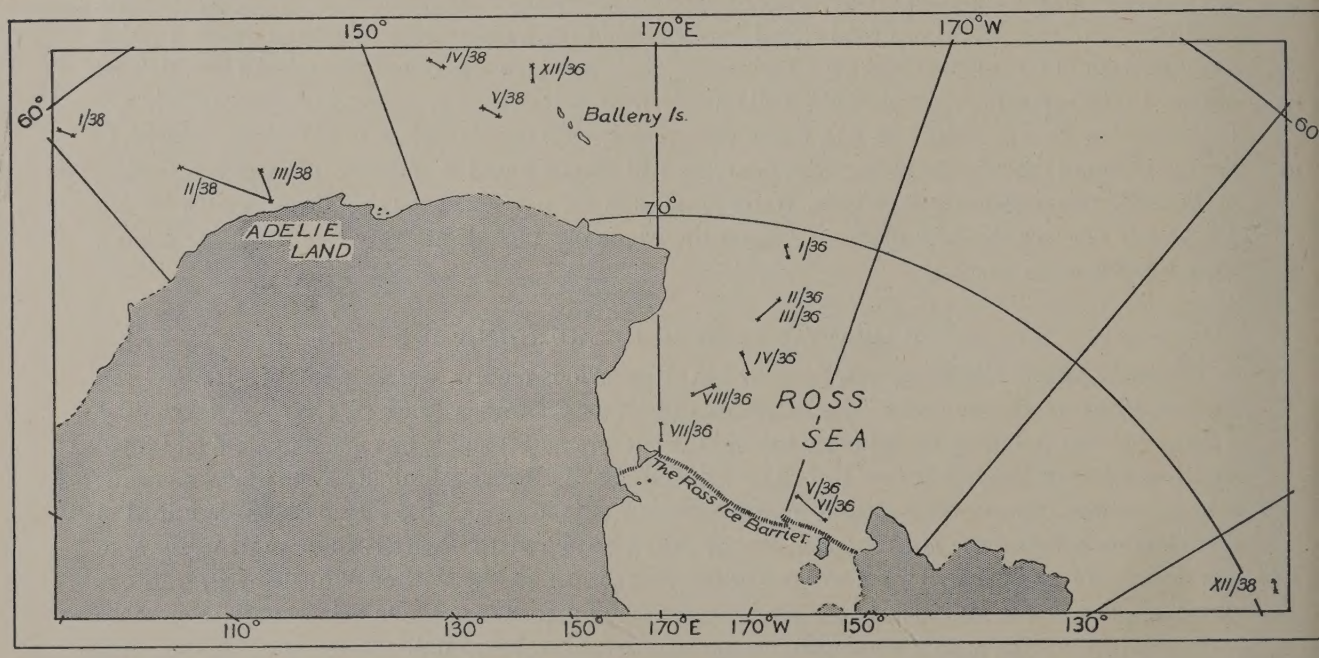


Fig. 1 (*b*).

Fig. 1. Oceanic soundings. Positions between which continuous soundings were obtained with the 'Acadia' recorder. (*a*) Near the Falkland Islands, across the Burdwood Bank and off the western entrance to the Magellan Strait. (*b*) In the Ross Sea, approaching and leaving the vicinity of Adélie Land, and north-west of the Balleny Islands.

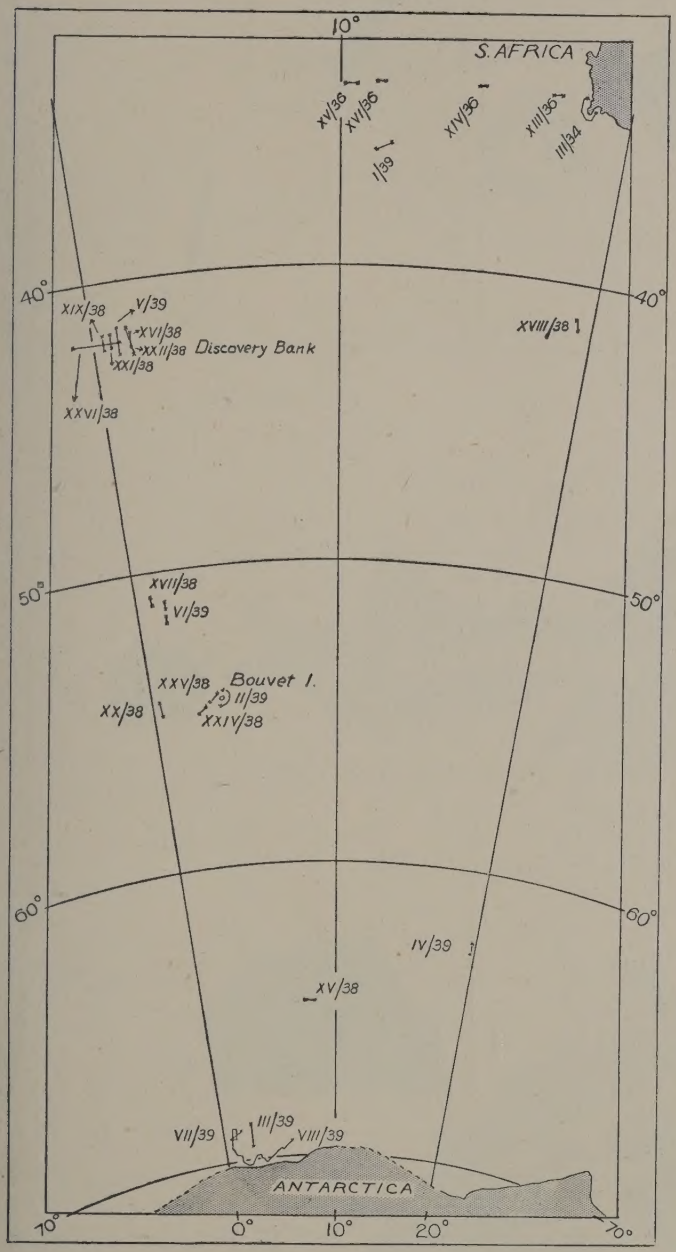


Fig. 2(*a*).

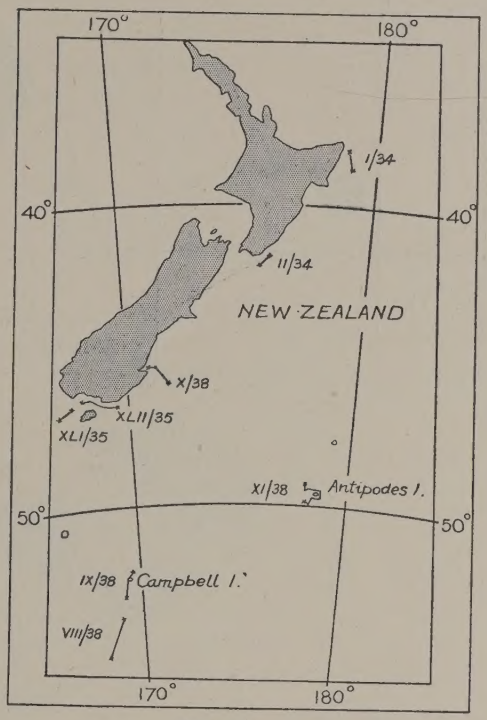


Fig. 2(*b*).

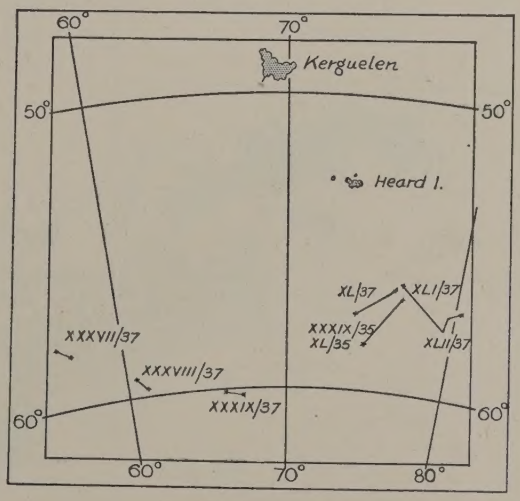


Fig. 2(*c*).

Fig. 2. Oceanic soundings. Positions between which continuous soundings were obtained with the 'Acadia' recorder. (*a*) In the area covered by the repeated cruises south and west of South Africa. (*b*) Off New Zealand and in surrounding waters. (*c*) Across the Kerguelen-Gaussberg ridge.

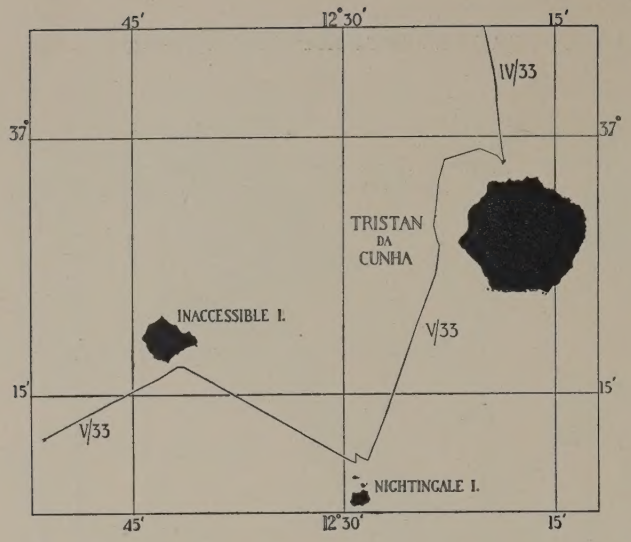


Fig. 3(*a*).

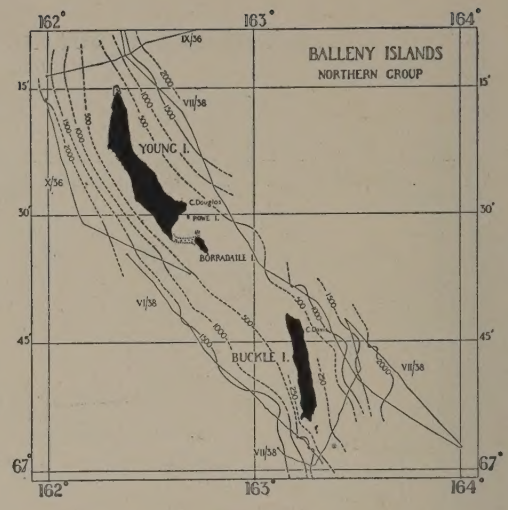


Fig. 3(*b*).

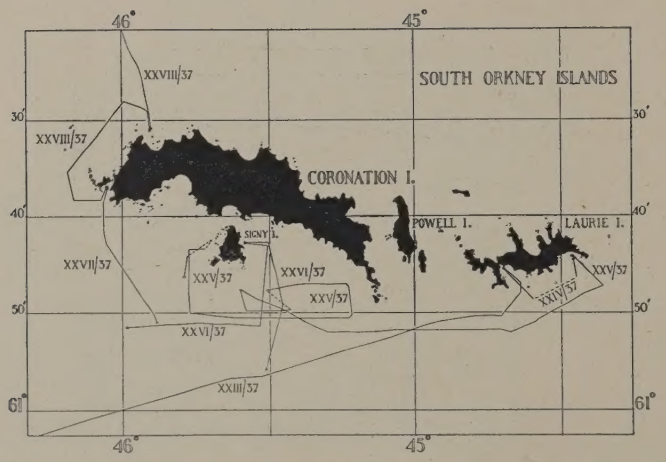


Fig. 3(*c*).

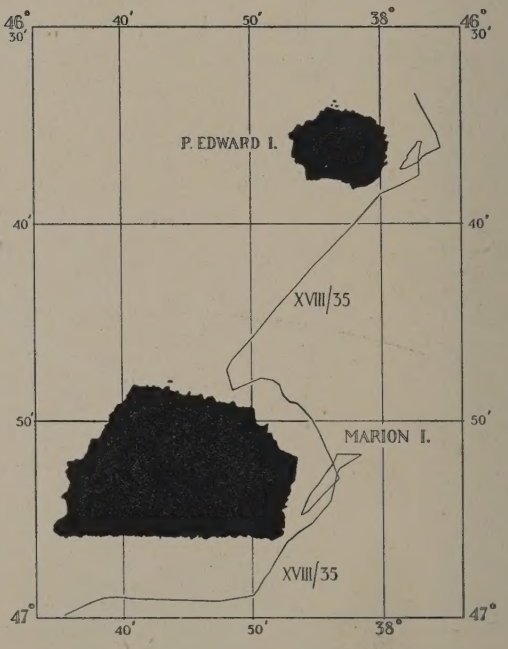


Fig. 3(*d*).

Fig. 3. Soundings during hydrographical surveys: continuous records. (*a*) Tristan da Cunha group: approaching Falmouth Bay, Tristan da Cunha, and from thence to Nightingale and Inaccessible Islands. (*b*) Balleny Islands: running surveys of 1936 and 1938, together with contours. (*c*) South Orkney Islands: completion, in 1937, of the earlier running survey of 1933. (*d*) Marion and Prince Edward Islands: 10 hr. continuous recording during an examination of these islands in 1935.

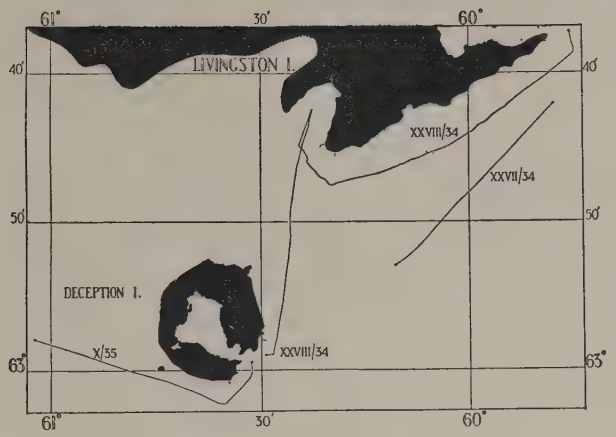


Fig. 4(*a*).

Fig. 4(*b*).

Fig. 4(*c*).

Fig. 4. Soundings during hydrographical surveys: continuous records. (*a*) Deception and Livingston Islands: recordings made during the running survey of the South Shetlands in 1934–5. (*b*) Livingston, Greenwich and Roberts Islands: recordings made during the running survey of the South Shetlands in 1934–5. (*c*) Nelson and King George Islands: recordings made during the running survey of the South Shetlands in 1934–5 and 1936–7.

## CORRECTION OF ECHO SOUNDINGS

As was stated in our earlier report, echo sounding saves a tremendous amount of time, and at moderate or great depths it is more accurate than sounding by wire. The tables compiled for the Hydrographic Department by Matthews for correcting the speed of sound in sea water have been much amplified since our previous report, as a result of the acquisition of considerably more hydrological data, and the new edition of 1939 contains a more accurate delineation of the increased number of areas for which correction tables are now available. As this new information was not available for use on board the 'Discovery II' before the end of her last commission it has been of interest to note that the original tables in use on board, most of which had been compiled from our own hydrological observations, by the methods shown in the first edition (1927) of Matthews's tables, vary only slightly from the more recent publication. The difference after correction by the new tables is in most instances so small (usually not more than 1 or 2 fm. in 2500 fm.) that it has not been considered worth while to re-calculate the many thousands of soundings involved, especially as an error of 1, 2 or even more fathoms may easily occur, either in reading off the soundings direct from the recorders or from the method used for timing the echo of the old 'listening' receiver. In the latter instance it was not possible at the greater depths to read to a greater degree of accuracy than $\pm 0{\cdot}005$ sec.—equivalent approximately to an error of $\pm 2$ fm. This accuracy, however, was difficult to attain and it is probable that the minimum error was more nearly $\pm 4$ fm. Since the accuracy of the soundings also depended greatly on the speed of the machines or recorders, periodic checks were made with an accurate stopwatch, and a rating error noted if the speed was greater or less than the normal. An error, however, which was difficult or almost impossible to detect arose in reading off the depths from the recorders. This reading off can be done in two ways: (*a*) The depths can be read directly off the wet paper as it passes the scale on the recorder, or (*b*) the paper can be dried and the soundings read off at any time afterwards with a special scale for the dry paper. Each method has its advantages but it was our practice to use method (*a*) and enter the soundings in a special log-book. This enabled a complete check to be kept on the exact time of the sounding, since the minute markings on the records could be compared with a chronometer watch, and had the added advantage that an operator was always present when survey work was in progress, to report any sudden irregularity or approaching danger. Method (*b*) on the other hand did not require such a constant watch to be kept on the recorders, but had the serious disadvantage in the 'Acadia' recorder that whether the paper was dried artificially by the heater incorporated in the lower part of the tank face, or was allowed to dry naturally away from a strong light, the shrinkage of the paper on drying was not always even. This was especially so when the paper was dried artificially, and as a final check on the soundings was always required when they were used for survey work, the heater was disconnected and the paper allowed to dry naturally before storing. Even then there was the disadvantage that the final width of the dried paper might not always be exactly the same, on account of the varying humidity and temperature of the air.

When soundings are being obtained on moderate or steep slopes it is, theoretically, possible to correct for the errors thus set up. In practice, however, the problem is one of great complexity, and will be discussed at length later in this report. It is sufficient here to say that in general it has not been considered practicable to correct our soundings for slope error.

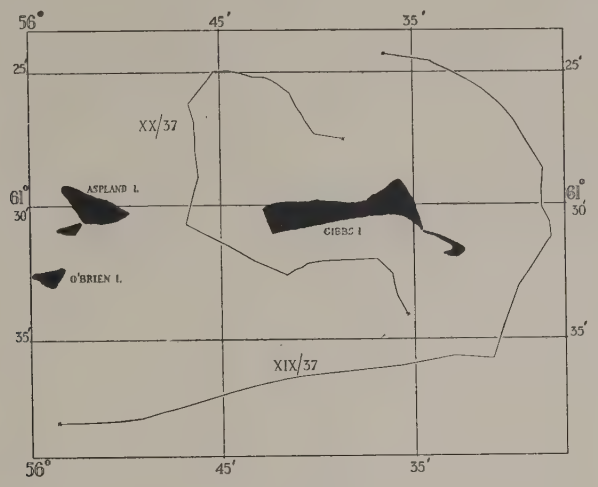


Fig. 5(*a*).

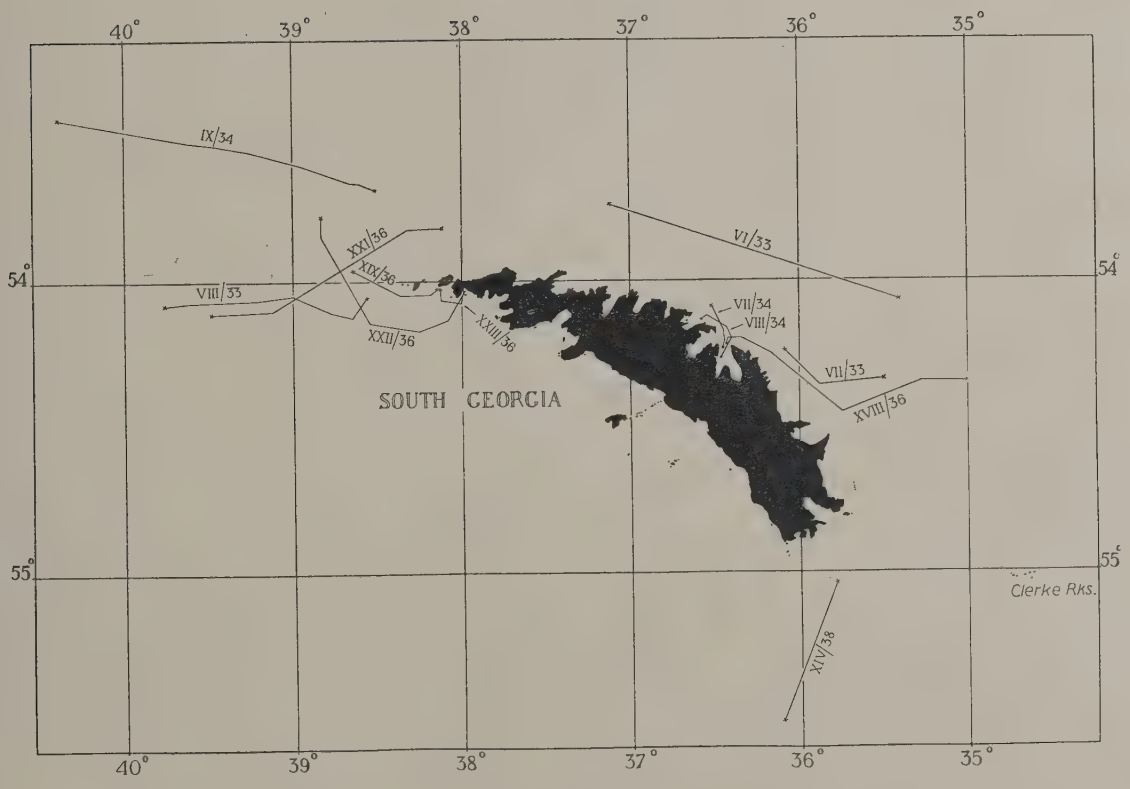


Fig. 5(*b*).

Fig. 5. Soundings during hydrographical and other surveys: Continuous records. (*a*) Aspland and Gibbs Islands: recordings made during a running survey in 1937. (*b*) South Georgia and vicinity: various recordings made between 1933 and 1938.

## DIFFICULTIES OF OBTAINING SOUNDINGS IN BAD WEATHER AND IN CERTAIN PARTS OF THE OCEANS

As a general rule the strength of the echo is inversely proportional to the depth of the water, but the echo is very much affected also by the physical condition of the water and the nature of the bottom, and it is specially important that the various causes of weak or inaudible echoes should be distinguished so far as they are known. Weak echoes can be caused by defects in the sounding set, and in the earlier years of our work it was assumed that weak echoes were generally attributable to such mechanical defects. During the later voyages of the 'Discovery II', however, it was found that difficulties in obtaining soundings could usually be traced to one or more of the following external causes: water noises, aeration, layering of the water, a soft or badly reflecting bottom, or an irregular bottom.

In bad weather the echo is liable to be obscured by a background of water noise associated with the ship's progress, and this may necessitate slowing down or heaving-to while sounding. In deep water, however, the echo strength was usually impaired during a gale, and this weakening often persisted for more than 24 hours after a severe gale had ceased and the water-noise background had subsided. This effect is probably due to the persistence of aeration in the surface water with consequent blanketing of transmission and echo. Such conditions rendered it difficult to obtain soundings in deep water even with the ship stopped.

Conclusive evidence that aeration can impede, or indeed completely cut off, the passage of supersonic sound in water was obtained on occasions when the ship's engine was put astern after letting-go an anchor. This sets up considerable local aeration, especially in shallow water, and when the ship moved over this patch of aerated water the echo trace on the M/S XIID recorder completely disappeared, returning only when the turbulence and aeration had subsided. With the deep-sea sonic set the strength of the signal appears to have been sufficient to overcome this local shallow area of aeration in depths of less than 50 fm. (91 m.).

Difficulty in obtaining an echo was also noticed on many occasions in certain latitudes even when weather conditions were such that perfect or almost perfect reception was to be expected. This applies especially to the neighbourhood of the Antarctic Convergence. The Convergence (see Deacon, 1937, and Mackintosh, 1946) is continuous round the Southern Ocean, and may be described simply as the line at which the Antarctic surface water sinks below the less dense sub-Antarctic water. In lines of soundings running for instance southwards it was usually found that the echo failed just north of the Convergence, especially where the latter was well defined, and was commonly very weak for a hundred or more miles to the south of it, even when it was ill defined. Deacon draws attention to the area of mixed water which lies just north of the Convergence and it is in this area that echoes become weak or have, on a few occasions, disappeared entirely. Further reference to Deacon (figs. 12, 13) shows that north of the Antarctic Convergence the discontinuity layers are well marked and have a pronounced horizontal or oblique trend. It is thus extremely probable that not only is the greater proportion of the outgoing soundwaves deflected by these layers of differing densities, but that the echoes from any soundwaves which may have penetrated in a direct line to the bottom are themselves deflected on their upward journey. Text-fig. 6, which is a section showing the vertical distribution of density in terms of $\sigma_t$, is a good example of these conditions which prevailed on the Greenwich meridian in February 1939, in positions where we noted a distinctly weaker echo. This diagram has been prepared for me by Mr A. J. Clowes and will eventually form part of a further report on the hydrology of the Southern Ocean.

It would appear that the weak echoes obtained to the south of the Convergence are attributable to the composition of the bottom deposit. A bottom of rock or hard clay will return a strong, clear echo,

but soft ooze will often fail to return more than a faint whisper, which only an operator with much experience can distinguish from other noises. The strength of the signal returning from a hard or rock bottom has often been sufficient to cause re-echoes, and many have been recorded from quite considerable depths. In one instance, on 8 March 1938, at St. 2277 (65° 19·6′ S, 81° 42′ W) a clear re-echo was heard at twice the observed depth of 2428 fm. (4440 m.). If the soundwave is of sufficient strength to echo again between the hull of the ship and the bottom at this depth, and then provide a clearly audible signal on its second return, it would appear that there should be ample reserve of power to provide an echo even from a moderately soft bottom. Immediately south of the Convergence, however, the deposit is almost pure diatom ooze and it apparently lies on the bottom as a very soft covering, the upper part of which is flocculent and comparable to a very thick soup. At St. 2519, in 51° 57·8′ S, 19° 32′ E, the bottom reversing water bottle of the deep hoist apparently hit bottom and brought up an excellent sample of this liquid ooze from 2865 m. (1567 fm.).

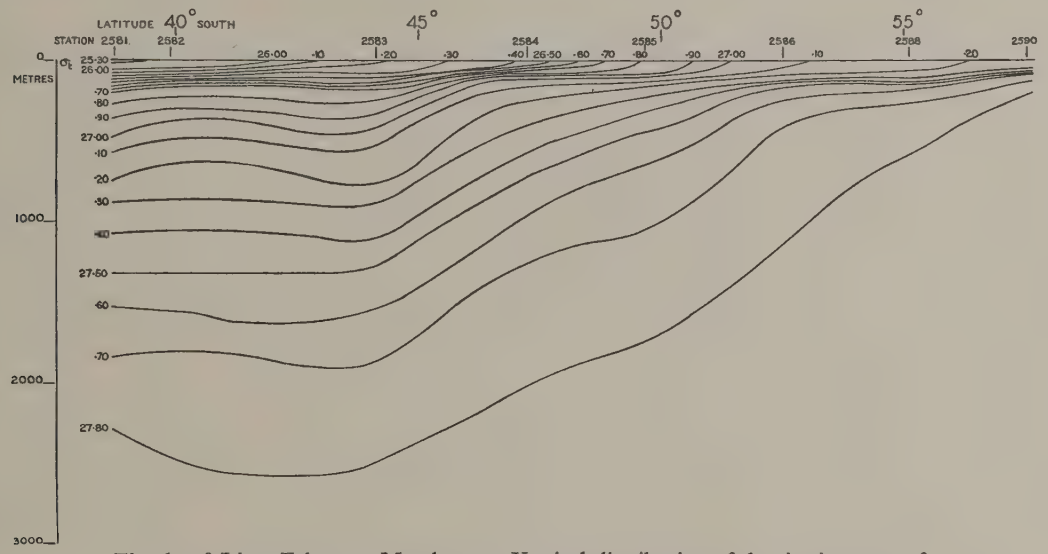


Fig. 6. 0° Line, February–March 1939. Vertical distribution of density in terms of $\sigma_t$. Antarctic Convergence in, approximately, latitude 49° 33′ S.

Generally, it may now be said that a belt of diatom ooze surrounds the globe in the southern hemisphere and that its northern limit approximates closely to the northern limit of the Antarctic Convergence (see Hart, 1934, pp. 185–6 and Deacon, 1945, pp. 11–20). We thus find in the neighbourhood of the Antarctic Convergence that there may be two important factors which will cause weak echoes, i.e. the horizontal trend of the discontinuity layers north of the line of the Convergence, and the bottom deposit of diatom ooze to the south. For a short distance north of the Convergence, when that line is displaced to its southern limit, it is therefore possible to have both factors, and under these circumstances sonic soundings have been proved to be almost impossible to obtain. It seems probable, however, that supersonic methods might be more satisfactory, as it is possible to obtain a better concentration of the beam of soundwaves. The belt of diatom ooze eventually fades out to the south into a belt of glacial mud from which it is possible again to hear a clear echo.

An area with faint or no echoes was also found by the second Byrd Antarctic Expedition, when their ship the 'Bear of Oakland' was on passage between New Zealand and the Ross Sea; though the latitude in which they were puzzled by the faintness of the echoes was south of any position in which we found the echo regularly to disappear or become very faint. Roos (1937, p. 582), in commenting on this occurrence, suggests that it might be due to a very soft bottom or to heavy rolling which, by

producing an excessive angle between the ocean floor and the face of the hydrophone tank, made the incoming echo less audible. The former explanation seems the more probable, for heavy rolling may take place anywhere in the Southern Ocean, and it was certainly not the cause of the faint echoes found by the 'Discovery II' near the Convergence, for, as mentioned above, the rolling could always be remedied by manœuvring the ship to suit the weather.

Another local area in which only weak echoes were received was found by the 'Discovery II' on the Greenwich meridian, south of the region of diatom ooze. It lay roughly between 54° S and 60° S and from the number of soundings which we eventually obtained during a series of repeated cruises in that area it seems likely that an extremely irregular bottom was the cause of our weak echoes. Rapid changes in depth were experienced and on one occasion the depth shoaled by nearly 2000 m. (1094 fm.) in 30 min., with the ship proceeding at normal speed. Changes of depth nearly of this magnitude were by no means uncommon, and attempts to take a record of some of the slopes with the 'Acadia' recorder were not very successful. On some occasions, indeed, the depth altered so rapidly that it was impossible to get an accurate reading even on the old 'listening' receiver. This problem of echoes from steep slopes will be considered in more detail in the next section of this report; but it may be stated here that owing to the extreme irregularity of the bottom now known to exist in many areas of the Southern Ocean, it seems probable that the weakness of echo strength reported often from south of the Antarctic Convergence-ooze area is more than likely to be due to this cause.

## SLOPE CORRECTION AND THE CONDITION OF THE OCEAN FLOOR

In general it appears to have been accepted that the soundwaves transmitted by sonic echo-sounding apparatus are reflected from the bottom at the point nearest the ship. If this is established, then with a level bottom, the depth recorded is the true depth at that point, but if the sea bed is sloping or comprises irregular features then the echo depth obtained is not the true depth and will require a correction for the angle of the slope. This correction is, of course, in addition to the normal corrections for draught and the speed of sound in sea water in different areas. In discussing the question of slope correction for sonic soundings, therefore, it is assumed that the expression 'echo distance' is the recorded depth which has been corrected for the speed of sound, etc., and that, unless otherwise mentioned, the soundwaves are reflected from the nearest point of the bottom.

The various methods of correction for slope have already been described at length in the *Hydrographic Review*, and Shalowitz (1930), Vanssay de Blavous (1930, 1933) and Hayes (1933) are some of the most recent contributors to this subject. Briefly it may be stated here that either the echo distance must be corrected for the slope of the bottom, or the position of the sounding must be moved up the slope until the actual depth at the new position equals the echo distance actually recorded. In a third method corrections embodying both the above systems can be applied. Text-fig. 7 is a simple diagram to illustrate the first two methods, and it will easily be seen that if $A$ is the position at which the sounding is taken then either the echo distance $AB$ must be corrected for slope by a plus correction to give the actual depth $AC$; or the position of the sounding must be moved from $A$ to $A'$ so that the echo distance $AB$ equals the actual depth $A'C'$. In this figure it is assumed that the slope of the bottom is regular; if it is not then the angle of slope must be determined for the point of observation and the correct echo distance or displacement calculated accordingly.

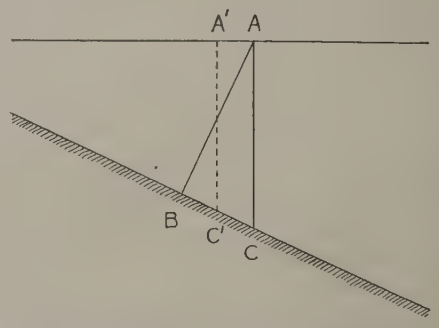


Fig. 7. Diagram to illustrate the theory of slope correction.

In general the angle of a slope can be determined approximately by plotting the series of echo distances obtained, at right angles to the contour lines, and measuring the angle of slope with a protractor.

In practice the echo distance can usually be assumed to be the actual sounding since, from the navigational point of view, the primary object is to establish the ship's position when making a landfall. Normally this implies fixing the ship's position with regard to the continental shelf, or charting her approach to shallow water from deep and vice versa, and there are few slopes where the correction for slope is sufficiently large to be shown on charts constructed on the scales usual for navigational purposes. In shallow water the correction becomes negligible. It should also be remembered that if soundwaves are reflected from the nearest point of the bottom, a ship approaching shoal water will obtain soundings from a position fairly well ahead if the slope is steep or moderately so. This is of distinct advantage to the navigator.

In the 'Discovery II' soundings were normally taken at intervals of one hour (or approximately 9 miles) and in these circumstances an accurate correction for slope is not possible. In the open ocean, however, the bottom is comparatively level and, even with soundings closely spaced, correction for slope is negligible unless the rise is greater than 1 in 10. When a ridge or bank was being crossed, however, we endeavoured to get as many soundings as possible, and, if the weather was favourable, to obtain a continuous record with the 'Acadia' recorder. Correction for slope then became possible, but it must be remembered that considerable errors may occur in fixing a ship's position in mid-ocean; in the most favourable circumstances it is doubtful whether accuracy can be greater than $\pm\frac{1}{4}$ mile, and it is probable that the error is of the order $\pm\frac{1}{2}$ to 1 mile. This fact, together with the necessity for plotting oceanic soundings on charts of a relatively small scale, makes it doubtful whether a correction for slope, either by displacement of position or by an addition to the echo distance, is practicable. It should be realized that a four-figure sounding, plotted on an oceanic chart of the usual scale and on Mercator's Projection, may cover an area of as much as 40–50 sq. miles in the latitude of 60° S and that this area increases to 100–120 sq. miles at the Equator. Thus it may not be possible to plot more than a very small fraction of the soundings from a bank or ridge, and from the navigational point of view correction for slope in oceanic waters is therefore of no value. To the geologist and geophysicist, however, the correct outlines of a ridge may be of definite use, but it remains doubtful whether correction for slope would greatly affect hydrological calculations on upwelling and the movements of the water masses.

The form of the beam of sound projected by the transmitter of a sonic echo-sounding set is of considerable importance in the interpretation of the soundings. It must be assumed that it is in the form of a cone in which the energy is at a maximum along the axis and fades out at the periphery. The amount of 'spread' or dispersal should vary inversely with the frequency of the soundwaves.

It is clear that an allowance must be made for a certain amount of spread. Hayes (1933, p. 154) states that with a relatively high-frequency sonic transmitter (presumably at 2000 cyc./sec.) the diameter of the beam at 2000 fm. (3758 m.) will be 1 mile. This is equivalent to an angle of spread of 14° and, presumably, is the limit of transmission of soundwaves of significant strength. Furthermore, the multiple echoes picked up on the recorder (see p. 56) must be attributed to echoes received from different directions. On the other hand, echoes were obtained from depths of more than 4000 fm. (7515 m.), and re-echoes from lesser depths; and this could hardly be expected were it not that the maximum sound energy is transmitted along the axis of the cone.

Some indication of the limit of dispersal of relatively high-frequency sonic transmissions is perhaps afforded by a sounding record obtained on one occasion when the anchor was being hove-up from 40 fm. (73 m.). The record showed a strong echo from the bottom and, as is natural with a small

object, a faint echo from the anchor. This echo, however, disappeared when the angle of the transmitter to the anchor was 48°, and a limit of spread of the soundwaves of significant strength might thus be indicated.

Difficulties in obtaining echoes from steep slopes may be due to the limited spread of the beam or to scattering, dispersal or absorption of the echo owing to the irregular form of the bottom which often prevails at moderate depths.

Before the advent of echo sounding deep-sea soundings were normally spaced some considerable distance apart and profiles drawn from these observations differ considerably from those constructed from lines of echo soundings at fairly close intervals. A good example of this is given by Sverdrup, Johnson & Fleming (1942, p. 18) where a profile including South Georgia and the South Sandwich Trench is shown, first as based on 13 existing wire soundings and then as constructed from 1300 echo soundings made by the German research ship 'Meteor' in 1926.[1] Our results are comparable to these, and in 1938–9, when a series of cruises was made between the latitude of 40° S and the ice-edge, on the Greenwich meridian, the profiles drawn for each cruise varied considerably, although the tracks were often within a few miles of each other. Two of these profiles are shown in Text-fig. 8 and for the latitudes between which they are comparable (i.e. 45–55° S) the tracks were within 3 miles of each other. From these it will be seen that although the main characteristics are similar, there is a considerable divergence in detail. These profiles, however, are again relatively simple when compared with the continuous records representing soundings every $2\frac{1}{2}$ sec., and although the latter do not cover a large area, they show a degree of irregularity in the sea bottom, especially to seaward of the continental shelf around Antarctica, which makes correction for slope quite impracticable. A section of such a record, which is typical of the sea bed in the neighbourhood of the Scotia Arc, is shown in Pl. XXVII, fig. 1. It was taken in waters of approximately 125–340 fm. (229–622 m.) in the Palmer Archipelago, off Graham Land, but in the interpretation of this it must be remembered that the vertical scale is much exaggerated, and that, since the paper feeds through the recorder at a fixed rate, the degree of exaggeration is dependent on the speed of the ship. To obtain the exact amount of exaggeration the speed of the ship (in knots) should be multiplied by 1·08. In this instance the speed was 9 knots and hence the vertical scale is magnified 9·72 times. Records taken on the Kerguelen-Gaussberg ridge and other such localities in the Southern Ocean show similar though less well-marked irregular features.

Apart from these irregularities in the bottom there are, of course, the difficulties previously mentioned in fixing the ship's position, and thus it has not been considered generally possible to correct our soundings for slope. In certain isolated instances, however, this correction was possible, as for instance when the ship's position could be accurately fixed from bearings on land which she was approaching almost directly up a slope. Such an instance was our approach to Tristan da Cunha in 1933 (Pl. XXVI, fig. 2), and in Text-fig. 9 is shown the profile of the slope drawn to true scale, together with the profile after correction for slope error. It is thought that on this occasion the ship's course towards the land was nearly enough at 90° to the bottom contours to justify slope correction, though this cannot usually be assumed without an adequate survey of the bottom.[2] As can be seen from the figure the correction is of little value for navigational purposes.

So far it has been assumed that echoes are only being received from one point on the bottom, but

[1] We are not fully in agreement with this method of presenting a section of the ocean bed with such an exaggerated vertical scale, since it tends to give a false impression of the relief of the ocean floor.

[2] In 1937 the International Hydrographic Bureau at Monaco circulated a questionnaire which, among other queries, asked the Hydrographic Departments of their member states whether their echo soundings were corrected for slope before insertion on the charts. From the replies received it appeared that very few countries applied slope correction and that many considered the practical error far to outweigh the advantages of such a correction.

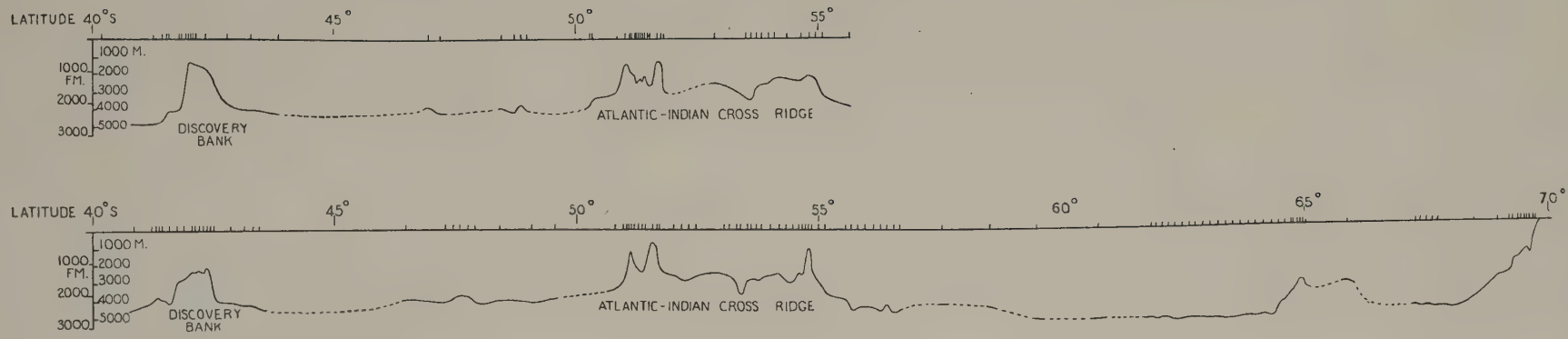


Fig. 8. Profiles of the bottom constructed from soundings taken during two of the repeated cruises on the 0° line of stations in 1938–9. Between the latitudes of 40° and 55° S the maximum difference in longitude was 3 miles. Vertical scale, ×40. Positions of soundings are marked on the horizontal scale.

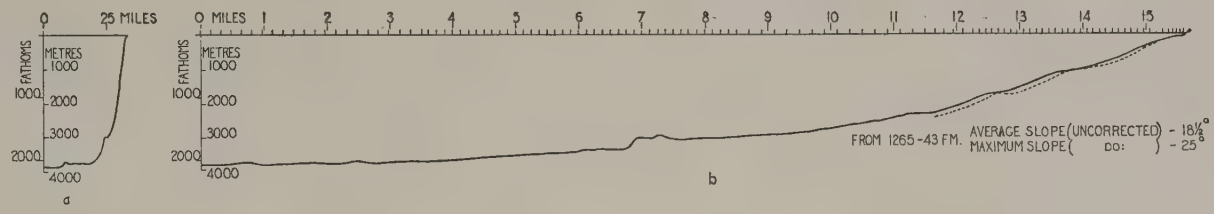


Fig. 9. Slope of bottom approaching Tristan da Cunha from the north. Positions of soundings are marked on the horizontal scales. (*a*) Vertical scale, ×25. (*b*) True scale, based on 116 depths in a distance of 15·5 miles. Dotted line shows true line of bottom after correction of soundings for slope error.

in view of the diverse character of the sea bed, as revealed by the automatic recorder, and the assumed spread of the soundwaves from the transmitter, it appears obvious that echoes may be received simultaneously from more than one point. A large number of records from the 'Discovery II' show such multiple traces (see Pls. XXVII–XXIX), and it will be obvious that this 'third dimension' introduces further complications in the interpretation of the records. It would appear impossible, except in certain isolated instances, to determine the relative positions of the points from which the echoes are being received, since with the conical spread of the transmissions these multiple echoes may be from points on the bottom ahead, astern, or on either beam of the ship. The few exceptions are the records which only show two traces and which probably result from crossing a simple but well-defined narrow valley or depression. As shown in Pl. XXX, fig. 4, these traces appear on the record in the form of 'crossovers'.

If it is assumed that the echo returns from the nearest point on the bottom, then a ship crossing a depression of the form shown in Text-fig. 10*a* will receive echoes at $A$ from $A_1$, at $C$ from $C_1$, and at $B$ from both $B_1$ and $B_2$. It is probable (and is assumed here) that only one echo would be distinguishable

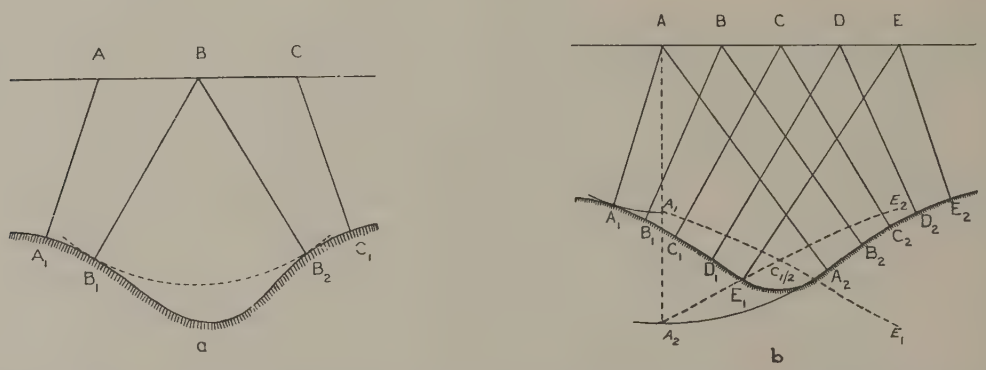


Fig. 10. Diagrammatic representations of sounding across a narrow valley. (*a*) Transmission and echo assumed to be narrow parallel beams. (*b*) Transmission spreading, and two echoes being recorded as in actual practice.

as such with the 'listening' gear, and it follows that echoes from the deepest part of the depression would be missed, and the profile of the bottom could only be assumed to take the form represented by the dotted line. The recorder however is more selective and sensitive than the human ear and it can distinguish echoes from points at different distances. It seems very probable that the 'simple cross-over' of the kind shown in Pl. XXX, fig. 4, is in fact the result of crossing a depression of the type shown in Text-figs. 10*a* and *b*. That is to say the 'crossover' is not a precise representation of the actual profile of the bottom but almost certainly represents echoes received simultaneously from both sides of a depression. In Text-fig. 10*b* positions $A$, $B$, $C$, $D$ and $E$ are presumed to be equally spaced points on the ship's track. It must be remembered that in practice continuous soundings are being taken between these points, but the points shown are sufficient to illustrate our theory. At position $A$ echoes are being recorded from $A_1$ and $A_2$, the latter being weak. At $C$ the echo strength from $C_1$ and $C_2$ is nearly equal and at $E$ the signal being received from $E_1$ is now the secondary trace and will probably be of just sufficient strength to give a recording under good conditions. From this it will be seen that a rounded, or U-shaped, depression may be recorded as a V-shaped 'crossover' as represented by the pecked lines in Text-fig. 10*b*, and that analysis of such a 'crossover' may give a more accurate representation of the shape of a depression on the bottom than can be obtained by the 'listening' gear.

It should perhaps be pointed out that these 'crossovers', or simultaneous echoes from a valley, can only be recorded when the two echo distances are within the range covered by the width of the record paper which, in our recorder, was equivalent to a depth of 250 fm. (457 m.). If the difference is outside these limits, 'phasing' to bring the second echo on the record will only result in the loss of the one originally being recorded. Normally the differences in echo distances at a 'crossover' are small and it is seldom that they exceed 150 fm. (274 m.). The average, for uncomplicated records, appears to be from 50 to 100 fm. (91–183 m.) but many of them fade out within smaller limits. It seems probable, therefore, that the simple 'crossover' effect is obtained only when crossing a fairly shallow depression or valley, which at the same time is comparatively narrow. It would seem also that the absence of a secondary echo from a wider valley at moderate depths is further evidence of a possible limit to the spread of soundwaves from a sonic transmitter.

In oceanic sounding with the recorder, multiple traces do not appear on the record from depths much greater than 2000 fm. (3658 m.) and are seldom recorded from shallow water of less than 100 fm. (183 m.), or from the continental shelf. On the other hand, records from various depths between 2000 and 3000 fm. (3658–5486 m.) mostly show the bottom as a flat plain; it is in the depths between 1000 and 2000 fm. (1829–3658 m.) that the greatest variety of bottom in the Southern Ocean is met. These really interesting regions are mostly in mid-ocean and on known but ill-defined ridges, but owing to the great irregularity of the bottom echoes are faint and difficult to record except in very fine weather—a condition which is not normally satisfied in these parts—and thus we have not been able to obtain more than a few good records. It is on these records, however, that the greatest number of multiple traces is to be found (see Pl. XXIX, fig. 1), and it is probable that the failure to obtain good results is for the most part due to the very steep slopes and to a diversity of features which causes scattering of transmissions and echoes. Limitation in the angle of spread of the transmissions may be a contributory cause when a slope is very steep and comparatively simple.

Soundings are not always difficult at intermediate depths, and some good records were obtained by the 'Discovery II' on the Antarctic continental slope, especially on the Greenwich meridian in March 1939 (Pl. XXVI, fig. 3). Here the slope is peculiarly free from complexities, and it is further discussed in a later section (pp. 86 to 88).

In the waters adjacent to the Scotia Arc an exception is found to the general rule that multiple traces are not usually recorded from depths of less than 100 fm. (183 m.). Areas such as the continental shelf around South America and the Falkland Islands, the Burdwood Bank, the approaches to South Africa, Australia and New Zealand, and other shallow areas show, on the whole, a remarkably level bottom sloping up gently towards the land. In the shallow water off the Scotia Arc conditions are quite different, and the bottom is extremely varied, though perhaps not quite so irregular as in the slopes at intermediate depths. 'Crossovers' on sonic records are common but are of small extent, and there are very many steep slopes. Instances, however, of more than two traces from these shallower depths are rare.[1] An example of this very varied bottom from the Palmer Archipelago has already been mentioned (see p. 54 and Pl. XXVII, fig. 1), and more will be given when the running surveys of the South Shetland Islands are dealt with (pp. 79 to 81).

[1] A possible explanation of the absence of multiple traces on records from waters of less than 200 fm. (366 m.) in depth here may be that the spread of the transmission at this depth is not sufficient for echoes to be recorded from other than the nearest point of the bottom. It is probable that the bottom is no less varied than that of the intermediate depths between 200 and 2000 fm. (366 and 3658 m.) but at these greater ranges the spread in the transmission will allow features which are not directly below the ship to be recorded.

## COMPOSITION OF THE BOTTOM

It is an established fact that the composition of the sea bed has an appreciable effect on the strength of the echo. We have already mentioned the difficulty of obtaining soundings in deep water in certain regions where the bottom is very soft, but with a hard bottom re-echoes can often be obtained down to moderately great depths. An instance of this has also been quoted (p. 51) and there were many other occasions when re-echoes were obtained from lesser depths. In deep water the automatic recorder cannot record both echo and re-echo unless, by chance, the re-echo falls in the same phase as the first echo, i.e. an echo from, say, 1050 fm. (1920 m.) and a re-echo at 2100 fm. (3840 m.) will fall in the phases 1000–1200 fm. (0–200 fm. on the phasing dial) and so be recorded simultaneously on the paper. An example of this from soundings of 890 to 1000 fm. (1628 to 1829 m.) is shown in Pl. XXX, fig. 2. On the other hand an echo from, say, 1275 fm. would be picked up in the 200–400 fm. phase, and its re-echo at 2550 fm. in the 400–600 fm. phase. In shallow water of 50 fm. (91 m.) or less, with a bottom of rock or hard sand, as many as four re-echoes have been recorded with sonic transmissions. Similar records have been obtained in shallow water with the M/S XII D recorder, though with the supersonic transmissions the number of re-echoes does not appear to be so great. The reason for this is almost certainly that the faces of both the deep-sea transmitter and hydrophone were exposed to the sea, whereas the supersonic transmitting and receiving tanks were secured *inside* the hull plating, which at this point was 1 in. in thickness.

For some years it has been known that supersonic transmissions in very shallow water could detect an overlay of mud, silt or sand on rock. Records from many parts of the world have been obtained with Messrs Henry Hughes and Son's machines, with the British Admiralty system of transmission, but references to these in the meagre literature on echo sounding in this country appear to be scarce. Among the few illustrations traced are portions of two very good records taken respectively in Canada (Lake St Peter, Quebec) and Denmark (Aarhus). Portions of these records were published in Messrs Hughes' private journal, *The Husun Review* (1936), but the reproduction is not sufficiently clear to show the depths at which they were taken. It appears fairly obvious, however, that they were in very shallow water. Another series, but with the depth scale clearly marked, shows overlays at 5–18 m. (3 to 10 fm.), and forms the illustrations to a report on the survey of Lake Windermere in 1937 by Mortimer & Worthington (1940). Chapman (1944) has shown echo-sounding records taken in water of depths up to 10 fm. (18 m.). These were taken during a survey of the British Coasts, primarily to determine the extent of the beds of the seaweeds of the genus *Laminaria*, but it might be expected that some indication would be seen of the presence of more than one layer of bottom deposit. Unfortunately from the echo-sounding point of view no depth scale is given, and this, together with the difficulty of reproducing such records clearly, makes it doubtful whether these illustrations are of much value for the determination of the composition of the bottom. Re-echoes are common but in one instance only does there appear any possibility that the soundwaves have penetrated beyond the surface of the bottom, and even this example (Chapman, pl. i, fig. 1) is open to several interpretations. As to work in other countries Th. Stocks (1935) has given an account of experiments in the Baltic, at depths of 11–22 m. (6–12 fm.). The echo-sounding set used here, the Debeg 'Radiolot', differed from the British Admiralty supersonic system in that the oscillation of a system of quartz plates was used as the source of the transmissions, and the returning echoes were observed directly as spots of light on a scale. It is claimed for this sounding set that the angular spread of the beam did not exceed 10°. From the illustration in Stocks' paper (fig. 3) it would appear that multiple spots of light were received, from a single transmission, over a portion of the scale covering a total depth of approximately 4 m. (13 ft.) and commencing at a reading of 15·5 m. (51 ft.). As the normal echo from one transmission,

at a depth of 182 m. (100 fm.), gave a single spot of light on the scale equivalent to a depth of 1·5 m. (5 ft.) these multiple spots have been interpreted as echoes from successive layers of the bottom deposit.

This may be correct, for the greatly increased frequency of the short-wave quartz transmitter (slightly more than twice that of the Admiralty system) may allow of greater penetration, but without the evidence provided by a permanent record there must remain an element of doubt in this assumption.[1] With the British Admiralty system of permanent recording there does not appear to be an instance published of the soundwaves penetrating more than what is apparently a single overlay on a harder bottom. Stocks (1935) and Rust (1935) have pointed out that the correct width of each layer in the deposit could not be accurately assessed, since the velocity of sound in the respective media was certain to show a difference from that determined for sea water. Theoretically this is true, but it is doubtful whether the accuracy in reading off depths from a visual light scale would be in itself sufficient to warrant an exact measurement being given for the extent of each layer. In practice it is doubtful whether a change in velocity would have much effect even on the measurements obtained by permanent recording at the very shallow depths mentioned, and it is probably true to say that the measurements of the extent of an overlay, obtained from a permanent record, would not be far from the actual figures. Confirmation of this could only be obtained from cores of the bottom deposit taken at the time when the soundings are recorded.

Rust (1935) mentions that layering in the bottom sedimentation has been detected with sonic transmissions but he does not give any particulars. No account of any such occurrence appears to have been published in this country but it is known[2] that in 1935 H.M. Survey Ship 'Challenger' obtained an excellent record of mud overlying rock near Trinidad, in the West Indies. The echo-sounding set used was the ordinary Admiralty pattern sonic set for shallow water, but with the addition of a recorder. The depth of water over the mud varied between 90 and 100 fm. (165 and 183 m.) and the depth of the mud itself from 180 to 240 ft. (55 to 73 m.). The record, unfortunately, was not retained after the completion of the survey. A careful examination of the many records we possess from the 'Acadia' recorder fails to show any such definite evidence that the soundwaves penetrated the bottom deposit. Admittedly, the great majority of these records were made in depths of water much beyond the range at which layering has hitherto been detected with supersonic equipment; but with the sonic transmitter and hydrophone both exposed to the sea it had been thought that if as many as four re-echoes could be recorded from shallow water, then there was a reasonable chance of the sound penetrating beyond the immediate surface of the bottom. The attenuation of the soundwaves from the deep-sea transmitter, however, was very great, and as can be seen from some of the records shown in Pls. XXVI–XXX the echo marking which thus results from a normal echo may easily cover any trace of an echo from a harder layer below the surface of the bottom. Among the records which were closely examined are certain peculiar recordings of fairly flat bottoms which might be considered as evidence of layering. The spread of sonic transmissions, however, is such that these secondary traces may well have their origin in other features of the bottom, at depths of more than 100 fm. (183 m.), and although there remains an element of doubt in some instances, these records have generally thus been interpreted.

We have been equally disappointed in such few records as remain from the M/S XII D recorder. The great majority of these have faded (see Appendix I, p. 97) and although the contour of the bottom was pencilled or inked-in shortly after the record was dry (see Plate XXXI, fig. 2), little else remains, except

[1] Conversations with the Marconi International Marine Co., Ltd., confirm our doubts on this point. The Marconi Co. have much experience of visual recording by light in conjunction with a quartz transmitter (or projector) and are not by any means prepared to assume that multiple flashes on the scale are echoes from successive layers of the bottom. In fact, they consider that the presence of such multiple effects (which to them is a well-known occurrence) is more probably caused by attenuation of the reflected soundwaves, owing to a rough or confused bottom.

[2] Private communication to the author.

on some records where there is an indeterminate marking below the lines. On the few that have remained on the whole fairly legible there is no definite evidence of layering, although in one or two instances it is just possible that this has been recorded. Our records, however, were very seldom taken in waters as shallow as those previously mentioned; shallow water to us usually meant depths of 30 to 50 fm. (55–91 m.), and even in enclosed anchorages in the Antarctic, where an overlay of glacial mud could reasonably be expected, we were mostly compelled, from lack of accurate information, to anchor in depths of water varying from 25 to 40 fm. (46–73 m.). In addition it must be remembered that our supersonic transmitter and receiver tanks were mounted inside the hull plating, with a consequent loss of signal strength. In the instance quoted above of the survey of Lake Windermere the transmitter and receiver used were protected only by a thin sheet of metal; for the other records shown in *The Husun Review* nothing is known about the thickness of plating below the tanks. It is probable that the face of the quartz transmitter referred to by Stocks was in contact with the sea, but even if it was protected it is unlikely that such protection was more than a very small fraction of an inch in thickness.

The loss of records through fading may thus be serious, for they cannot now be subjected to a critical examination. Such work can scarcely be done during a running survey, for the logging of soundings, either direct from the recorder or from the dried paper after the day's work, leaves little or no spare time. It is therefore to be hoped that as the result of the experiments now being made, a more permanent marking on the records will be achieved in future.

## TERMINOLOGY OF SUBMARINE RELIEF

The need for a systematic nomenclature for the features of the sea bottom became apparent many years ago and the first serious attempt to provide for such a need appears to have been made by Petermann, in 1877. Between then and 1899 Agassiz (1888), Murray (1895) and Supan (1899) contributed greatly to the subject, and in the latter year, at the Seventh International Congress of Geographers in Berlin, consideration was given to certain principles to be applied in naming the features of the sea bottom. These principles were formulated by Krümmel and Mill on a geographical basis and have become the foundation of most of the modern nomenclature. In 1932 Littlehales described the first and second magnitude forms of the ocean bottom together with an appropriate terminology which had by then attained international currency. In the same year the International Hydrographic Bureau published their *Terminology of Submarine Relief*.

In 1936 an International Committee was formed to report on the 'Criteria and Nomenclature of the Major Divisions of the Ocean Bottom', and their findings were published by the Association d'Océanographie Physique (1940). The Committee considered many suggestions, but there is still much confusion over some of the terms which should be applied to the relief of the ocean floor. In the present report we have adhered generally to the terminology of Littlehales for the description of the submarine relief, and for the nomenclature of the different divisions of the sea bed in the southern seas to the terms hitherto generally adopted in the publications of the Discovery Committee. Some of these terms were described by Mackintosh (1940) in his article for the International Committee. We are not, however, altogether in agreement with the use of the term 'swell', which now appears to be fairly widely used as the definition of a rise which separates two deep basins, and which has a saddle depth of 4000 m. or more. The original word proposed by German authorities to define such a feature of the bottom relief was 'Schwelle', of which the literal translation is 'sill', meaning a 'threshold'. It was to be additional to the terms 'ridge' and 'rise', which were already well established. The use of the word 'swell' as the alternative in English to 'Schwelle' may be intended to convey more accurately this conception of a slight rise or swelling of a few hundred metres in the bottom relief at the greater depths, as opposed to a more definite rise of, say, 1000 m.

The terms 'ridge' and 'rise', however, would appear to be sufficiently expressive to provide an adequate description of the bottom relief between the deep basins of the various oceans, but if it is considered really necessary to have this additional term we would then suggest that the word 'sill' is much preferable as the English version of the term 'Schwelle'.

## THE SCOTIA ARC (Plate XXIII)[1]

In our previous report on soundings (1932, pp. 214–9) much evidence was presented in support of an arcuate connexion between Tierra del Fuego and Graham Land, by way of Staten Island, the Burdwood Bank, the Shag Rocks, South Georgia, the Clerke Rocks, the South Sandwich Islands, the South Orkney Islands, Elephant and Clarence Islands and the South Shetlands. Such a connexion had long been forecast by some geologists, but evidence from rock specimens was scanty or even contradictory and, prior to the work of the Discovery Committee's ships, very little information was available from soundings.

The term 'Scotia Arc' was adopted on the suggestion of Mr J. M. Wordie (see Herdman, 1932, p. 214) but does not appear to have met with universal approval; Mosby (1940, p. 96), for instance, prefers the term 'South Atlantic Arc' and German authorities, such as Stocks (1937, 1939) and Wüst (1933), have persisted in the view that their term 'South Antilles' is more correct. Reasons have already been given (1932) for preferring the term Scotia Arc to that of the South Antilles and, as the name 'Scotia Sea' is generally accepted for the area around which the major portions of the Arc are grouped, it does not appear that the term South Atlantic Arc is a better alternative. In our opinion this latter name is also slightly misleading, and in this report the name Scotia Arc will be retained.

Between 1932 and 1939 many thousands of additional soundings in this area were taken by the 'Discovery II', and, by landings and dredgings, we have also been able to obtain relevant geological material. Samples of rock were obtained from the South Shetlands, parts of Graham Land and the off-lying islands to the north-west, Gibbs Island (near Clarence Island), and Saunders Island, in the South Sandwich group. Dredged material from near the Shag Rocks, from Clarence Island, and from four stations in the South Sandwich group completed the collection. Although the evidence from the South Sandwich group is inconclusive, Tyrrell's report on these specimens (1945) supports the theory, favoured by Suess and others, of a tectonic connexion between South America and West Antarctica along the Scotia Arc.

Tyrrell considers that the predominant basic lavas of the South Sandwich Islands show a closer affinity with the comparable rocks of the Antilles of North America than with those of the Andes, and he suggests that the South Sandwich Islands may not lie on the main line of the Scotia Arc, but may form an easternmost ridge parallel to and in echelon with it. In support of this he notes the south-eastward trend of the axis of South Georgia, and the northward extension of the 3000 m. contour (shown in pl. xlv of our previous report of 1932) leading down to the South Orkney Islands. Since the publication of that chart, however, further soundings have provided valuable evidence of a far more prominent ridge which appears to connect the South Orkney with the South Sandwich Islands (see pp. 73–4), and there seems little doubt that this represents the main line of the Arc. Unfortunately, we have had no new soundings to the south-east of South Georgia but, in our opinion, those already obtained are of sufficient density to preclude the possibility of a direct connexion between the South Orkneys and South Georgia.

[1] As in our earlier bathymetric chart soundings from sources other than the Discovery Committee's vessels are shown in Pls. XXIII to XXV as open circles. Our soundings up to May 1932 are shown as black dots; subsequent to that date crosses have been used to indicate the positions of 'Discovery' soundings. Since the scale is small it has not been possible to show all the soundings taken when they were closely spaced, or when continuous soundings were being taken with the recorder.

The existence of a continuous ridge between the South Sandwich and South Orkney Islands has been queried by Wüst (1933, pp. 44–5), on account of the percolation of Antarctic-Atlantic water into the 'South Antilles Sea', at a point half-way between the South Sandwich group and the South Orkneys. His facts are deduced from the potential bottom temperatures and in his illustration (pl. ii) he shows a break of approximately 90 miles in the ridge, centred about 34° W, where a depth of more than 2000 m. (1094 fm.) is to be expected. From our line of soundings along this part of the ridge in 1932 it would appear that if such a break does exist in this position then its maximum width must be considerably less than that deduced by Wüst. Our observations show that in the neighbourhood of the longitude in question there can only be a maximum distance of 20 miles over which depths of more than 2000 m. (1094 fm.) can be expected; in fact, the horizontal distance between the 1000 m. (547 fm.) contours is only some 40 miles at this point. It should also be pointed out that, in view of the extremely irregular form of the Arc in general and especially of the known complicated area west of 40° W longitude, it cannot be said that this one line of soundings gives a complete picture of the ridge at the point in question. It is, in fact, very probable that a system of parallel ridges will be found to exist here, similar to those found between Clarence Island and the South Orkneys. Some further observations on this subject have been made by Deacon (1937, p. 111), who shows that from the hydrological point of view the existence of low-bottom temperatures in the Scotia Sea may not necessarily be evidence of an inflow of cold bottom water from the Weddell Sea, but may well be due to the formation of cold bottom water in the deeper regions of the Scotia Sea which lie north and west of the South Orkneys.

Considerably more detail in the delineation of the Scotia Arc has been made possible as the result of the many further soundings taken by us in this area since 1932. The South Sandwich Trench,[1] which is perhaps the outstanding feature of the Arc, was crossed a further seven times between December 1932 and March 1937, and four of these lines of soundings were far to the south of any crossings previously made. We had always suspected that the Trench might extend farther to the south and west than the earlier soundings had shown, and it now seems certain that its south-western limit is not far from a position in 61° S, 26° W, with its line of curvature lying almost parallel to the line of the South Sandwich Islands. At the northern end soundings taken in December 1932, and August 1934, show that the deepest portion of the Trench extends about 60 miles farther west than hitherto determined, and that the 5000 m. contour now lies some 30 miles nearer to South Georgia, extending almost to the 4000 m. contour. The length of the Trench can now be stated with fair accuracy; at depths of more than 5000 m. (2734 fm.) it extends for approximately 650 miles and at depths greater than 7000 m. (3829 fm.) the length is approximately 500 miles. The maximum depth of 8264 m. (4519 fm.) obtained by the 'Meteor' in 1926 was not exceeded but, in December 1932, in 54° 57′ S, 29° 26′ W we obtained a sounding of 8200 m. (4484 fm.), which was 98 m. (179 fm.) in excess of our previous record of 8102 m. (4430 fm.) in 56° 33′ S, 24° 33′ W. In all the seven crossings made since 1932 we obtained fifty-five soundings of more than 5000 m. (2734 fm.) and of these thirty-one were of more than 6000 m. (3282 fm.), thirteen of more than 7000 m. (3829 fm.) and one of more than 8000 m. (4376 fm.). From the evidence now available it appears reasonable to assume that the Trench has a depth considerably in excess of 7000 m. (3829 fm.) for the greater part of its length, though it

[1] It is considered that the name 'South Sandwich Trench', in accordance with Littlehales's terminology, is preferable to 'South Sandwich Deep'. We are not, however, in agreement with the suggestion made by Wüst (1940, p. 20) and others that the deepest known parts of the Trench should be called Meteor Deep and Discovery Deep respectively. Since those soundings of more than 8000 m. were obtained, the 'Discovery II' has obtained a sounding of 8200 m. some 90 miles west of the 'Meteor's' greatest depth and nearly 200 miles distant from the greatest depth previously determined by the 'Discovery II'. A more complete survey of the Trench may well disclose even greater depths, especially if the recorder can be used, and it seems premature to give names to the deepest parts which so far happen to have been found.

will be noticed that at the southern end it narrows considerably. The distance between the 7000 m. contours at the northern end varies between 17 and 30 miles, whereas south of latitude 57° S the Trench gradually narrows from 15 to 4 miles in width between the same contours. It would have been of the greatest interest if continuous soundings could have been taken across the Trench with the recorder, but on no occasion was this possible. Four lines of soundings were run across it after the recorder had been fitted (in 1934 (2), 1936 and 1937), but on the two earlier crossings (a zigzag, or double crossing in April 1934, between the latitudes of 58° S and 59° 31′ S) the instrument was out of action, and on the later crossings, at the extreme northern and southern ends, bad weather precluded records from such great depths.

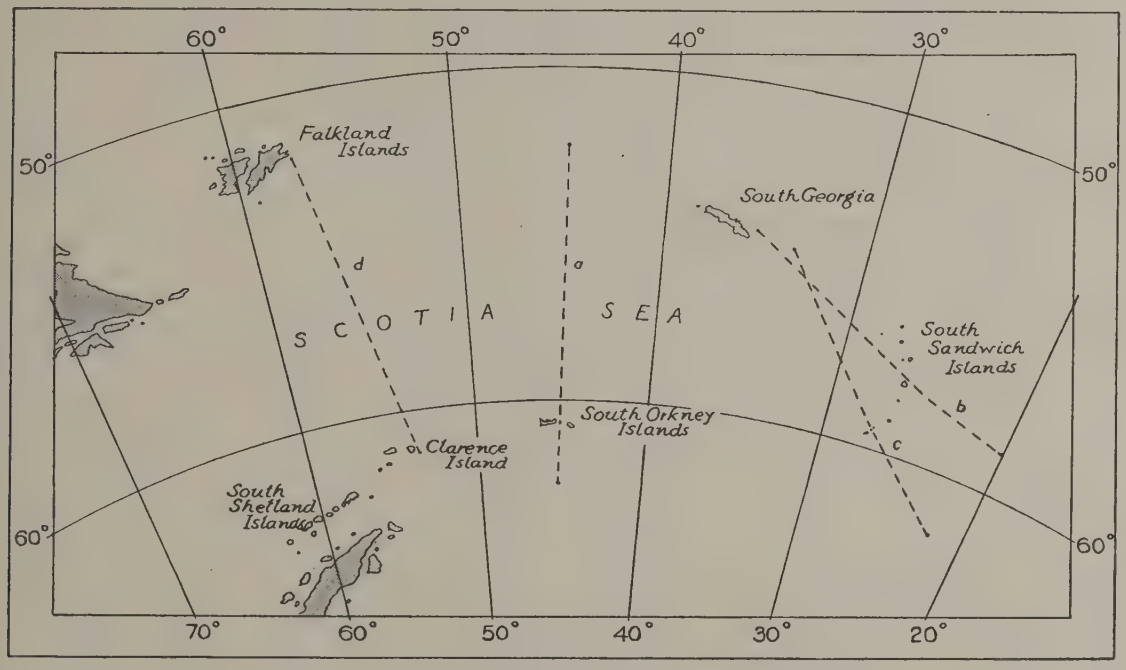


Fig. 11. Key chart showing positions of profiles in Fig. 12.

Another interesting feature of the soundings since 1932 is the discovery that the Burdwood Bank is separated from the main Falkland-Patagonian shelf by much deeper water than was formerly supposed. Eight additional lines of soundings were taken between the Burdwood Bank and the Falkland Islands and these have resulted in a marked change in the contours of this area (see p. 68).

It is now possible to construct four new profiles of the bottom in the area comprising the Scotia Sea and Arc (Text-fig. 11). Two of these cross the Scotia Sea from north to south and the remaining two run in east-south-easterly and south-easterly directions respectively from South Georgia. One of these (Text-fig. 12*a*), in approximately 45° W, extends for 620 miles and comprises 160 soundings. It crosses the well-defined ridge west of the Shag Rocks, illustrates the extensive folding on the northern side of the South Orkney Islands and shows the southward continuation of the South Orkney shelf to approximately 62° S. It should also be noted that the bottom just south of the Burdwood Bank-Shag Rocks ridge is likewise an area of considerable folding. The second cross-section (Text-fig. 12*d*), which is based on 107 soundings, runs from Cape Pembroke, Falkland Islands, to a position in line with, but slightly east of, Clarence Island, a distance of 575 miles. It shows some similar characteristics in that an area of considerable folding exists south of the Burdwood Bank—more

complicated indeed than in the area farther east—and in that the bottom rises steadily from the middle of the Scotia Sea towards Clarence Island; there does not, however, appear to be any evidence of folding just north of Clarence Island such as is a prominent feature of the bottom, for many miles east and west, a few miles north of the South Orkneys.

On the eastern side of the Arc the two new profiles of the sea bed begin east of South Georgia and north of the Clerke Rocks and, having crossed the Clerke Rocks-South Sandwich Islands section of the Arc in approximately the same position, continue in an east-south-easterly and a south-easterly direction. The profile shown in Text-fig. 12*b* commences in 54° 23·3′ S, 35° 30′ W, crosses the South Sandwich group slightly to the north of Saunders Island and continues across the South Sandwich Trench to 58° 50′ S, 20° 05′ W. There is a steady rise on the inside of the loop of the Arc to a well-defined ridge at the South Sandwich Islands, and beyond this the bottom shows a marked irregularity before dropping away abruptly into the Trench itself, across which a good line of soundings was obtained. The remaining section (Text-fig. 12*c*) begins slightly south and east of that just described, crosses the Arc in approximately 55° 15′ S, 33° W and, continuing through the South Sandwich Islands via the Douglas Strait, crosses the Trench in approximately 60° 30′ S, 25° 15′ W and finishes at 61° 55·2′ S, 20° 02′ W. The soundings between the South Sandwich Islands and the Trench unfortunately were few, owing to a breakdown of the transmitter, and although emergency repairs enabled us to get six extremely valuable soundings across the deepest part of the Trench, there was a further gap of some 60 miles in the line whilst repairs were again being effected. In the profile the bottom is shown as a dotted line for those periods during which the transmitter was out of action. A very good continuous record was obtained in the Douglas Strait on this occasion, though the maximum depth recorded—321 fm. (587 m.)—was nearly 100 fm. (183 m.) less than the greatest depth determined here during our survey of the South Sandwich group in 1930. Douglas Strait, which has been described by Kemp & Nelson (1931) in their account of our survey operations, lies between Southern Thule and Cook Island and is, geologically, an extremely interesting feature. It is a deep basin, with a maximum depth, so far determined, of 409 fm. (748 m.), and it is cut off at the entrance on either side by a ridge, on which there is an average depth of water of about 14 fm. (26 m.). There can be little doubt that Southern Thule and Cook Island originally were one large island and that this basin is the crater of an extinct volcano, an eruption of which probably separated the island into two. Our record in 1935 was taken on a line across the eastern side of the basin, and agreement with the contours previously determined was good.

In both the profiles just described it can be seen that the connexion between the Clerke Rocks and the South Sandwich Islands is not very clearly marked, although the deeper water of the western end of the South Sandwich Trench can clearly be seen at the beginning of each section. From this deeper water there is a well-marked rise to the line of the connexion, but of the connecting link itself there is little evidence here other than a rise of some 300–400 m. (164–219 fm.). This, however, when considered in relation to the extension of the Trench in a westerly direction, to a position north of the Clerke Rocks, may be held to constitute a connexion here; especially as there is considerable evidence of folding, such as is commonly found inside the loop on most of the other sectors of the Arc. The approach to the South Sandwich Islands from the west, both in the middle of the Group and at the southern end, is, however, an exception to the irregularity normally found inside the Arc. In each instance the bottom rises steadily towards the connecting ridge, as in the approach to Clarence Island (Text-fig. 12*d*), and it is probable that similar conditions prevail over the greater part of the northern side of the ridge between Southern Thule and the South Orkney Islands.

With the exception of those parts of the loop just mentioned it would appear that the slope of the bottom inside the connecting ridges of the Arc is, in general, steeper than outside. This is most

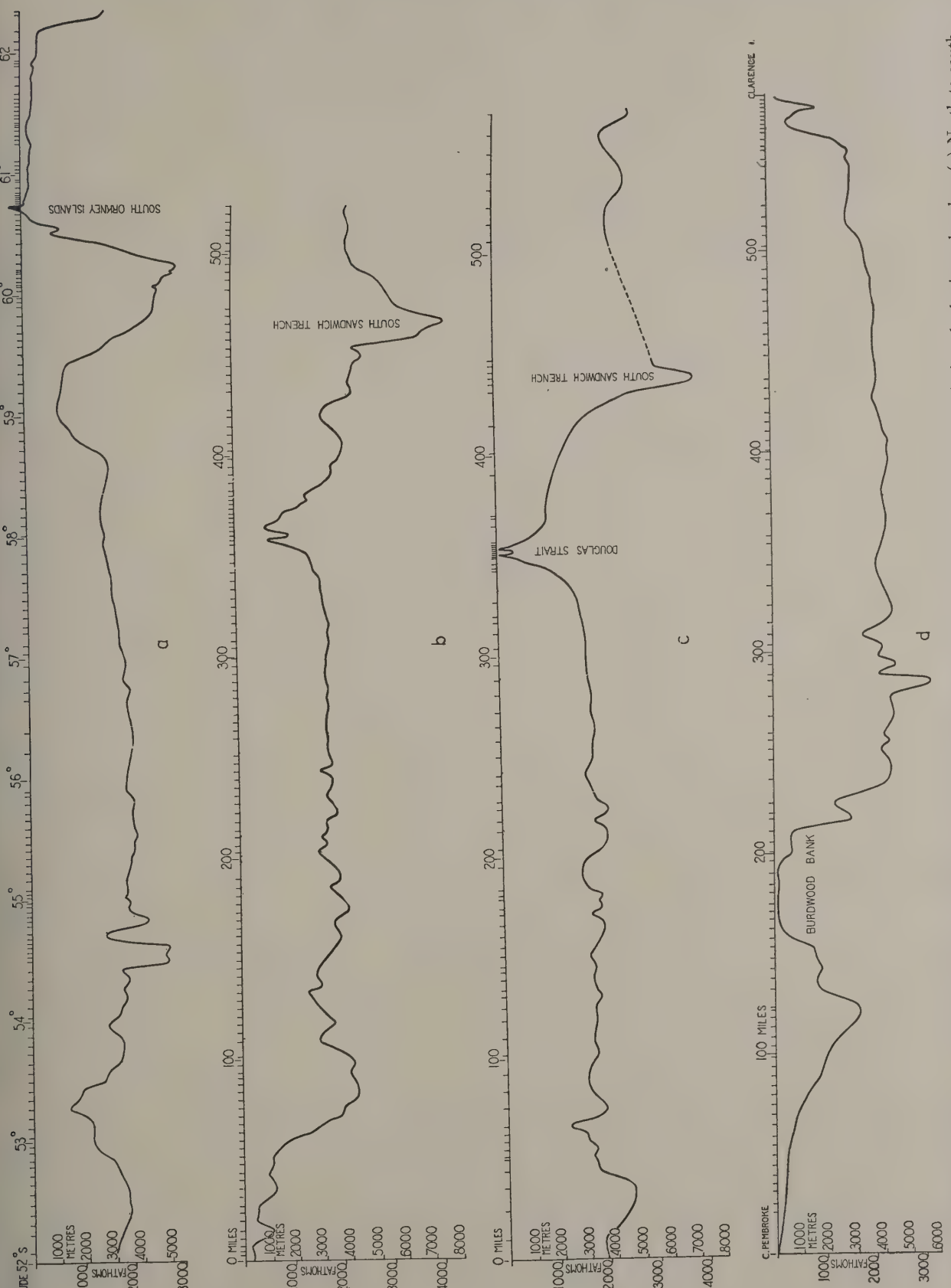


Fig. 12. Profiles of the bottom in the Scotia Sea and across the Arc. Vertical scale, ×25. Positions of soundings are marked on the horizontal scales. (*a*) North to south, between the latitudes of 52° and 62° 20′ S in, approximately, the meridian of 45° W. Based on 160 depths. (*b*) From 54° 23·3′ S, 35° 30′ W, across the South Sandwich Trench, to 58° 50′ S, 20° 05′ W. Based on 88 depths. (*c*) From, approximately, 55° 15′ S, 33° W, through the Douglas Strait and across the South Sandwich Trench, to 61° 55·2′ S, 22° 02′ W. Based on 131 depths. (*d*) Cape Pembroke, Falkland Islands to Clarence Island. Based on 107 depths.

noticeable in the region of the Burdwood Bank, around South Georgia, north-west of the South Orkneys and north-east of Elephant Island. The slopes off the South Orkneys are among the steepest we have met; they are certainly among the steepest slopes of any length from which we have been able to obtain a very good record, and we were fortunate to have fine weather in which to run the recorder when leaving Coronation Island, in a northerly direction, in February 1937. The record (see Pl. XXVI, fig. 1) covered 11 miles of the bottom, with a steady fall from the anchorage of 25 fm. (46 m.) to the edge of the shelf in 148 fm. (271 m.) and then an abrupt descent to a depth of 1514 fm. (2769 m.). The profile constructed from this record is shown in Text-fig. 13*a* with the vertical scale exaggerated 25 times and in Text-fig. 13*b* on the true scale. Soundings every minute were taken off the record to construct the latter, and the average gradient northward from the edge of the shelf, as determined graphically, is approximately 20°. The maximum slope here is approximately 25°.

Some shorter slopes of a similar magnitude have been observed on records taken in the channels of the Palmer Archipelago, during the surveys of the South Shetland Islands and in various channels leading seaward from Magellan Strait, but their length was generally only a fraction of a mile, and since the angle of approach to the contours was usually unknown, accurate analysis

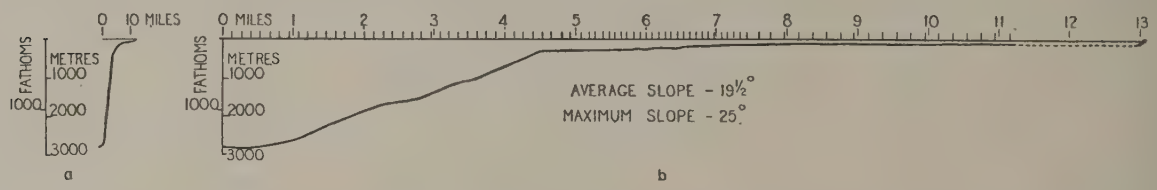


Fig. 13. Slope of bottom to the north, from Coronation Island, South Orkneys. Positions of soundings are marked on the horizontal scales. (*a*) Vertical scale, ×25. (*b*) True scale, based on 65 depths from continuous record.

has not been possible. In certain isolated instances, however, the density of soundings is such that a few contours can be drawn and the slopes which occur in these areas will be discussed in more detail in a later section of this report which deals with soundings taken during hydrographical surveys.

In these general remarks on the Scotia Arc it will be advisable, perhaps, at this point, to refer to some recent bathymetric charts which include this area. Stocks (1937), in one of a series of bathymetric charts of the Atlantic Ocean included in the 'Meteor' Reports, shows the contours of the eastern end of the Arc on a large scale. The western limit of this chart is the meridian of 30° W and the contours should, of course, be studied in conjunction with those of the area to the west; unfortunately, this chart, which covers the remainder of the Scotia Sea, was not published in Germany until 1941 and we have not, as yet, been able to obtain a copy.[1] The 'Meteor' soundings have, however, been published as lists of soundings (Maurer & Stocks, 1933) and we have used these in the compilation of our bathymetric chart. The depths obtained by the 'Meteor' which were shown on our original chart were only a small selection of soundings which had been supplied to the Hydrographic Department of the British Admiralty shortly after the return of the vessel.

In the eastern area which comprises the Arc, Stocks has based his contours mainly on one line of soundings obtained by the 'Meteor' in 1926 and on a selection of our soundings (presumably those which were published with our previous report or which have appeared in our Station Lists) together

[1] Since this was written we have obtained a copy of this chart. No contours are shown and most of the information was already known to us, but some hitherto unpublished soundings, taken by the whaling factory ship 'Walter Rau', provide valuable confirmation of our interpretation of the topography of the bottom in the neighbourhood of the South Orkney Islands.

with the further selection of our soundings which has been inserted on the relevant British Admiralty Charts. His interpretation of the outline of the northern and central portions of the South Sandwich Trench agrees therefore fairly closely with ours, although it lacks the confirmatory detail supplied by our more complete data. At the southern end, where all the soundings available are, with one exception, from the 'Discovery II', those used by Stocks, which are presumably those selected by the Admiralty from our lists and inserted in proportion to the scale of the relevant chart, are not quite sufficient in themselves to provide an adequate basis for bathymetric purposes. As we have shown in Pl. XXIII we consider that it is more probable that the 5000 m. contour, on the eastern side of the Trench, follows the line of the Trench to the south-west and that it does not join up with the small deep area of more than 6000 m. which lies approximately between the meridians of 22° and 23° W in latitude 61° S. In general the topography of the sea bed in this area appears to be extremely irregular and it is more likely that this secondary deep area, together with the area of more than 5000 m. in depth lying between 22° W and 25° W, in 62° S, are further evidence of the system of parallel folds which is so prevalent in other sectors of the Scotia Arc.

The Scotia Sea and South Sandwich Trench are also included in a bathymetric Map of Antarctica (1939) produced by the Department of the Interior, of the Commonwealth of Australia. As in Stocks's chart, this map is contoured in metres, and for the area in which we are concerned the contours in general follow closely those of our previous bathymetric chart, but a considerable number of amendments have been made to conform with our more recent work. This is most noticeable in the Burdwood Bank-Shag Rocks section of the connecting link, though the lack of a 500 m. contour here tends to give the impression that the Burdwood Bank is part of the continental shelf on which the Falkland Islands lie, rather than an integral part of the Arc, as is shown clearly on our present chart. The outline of the South Sandwich Trench agrees well with our latest interpretation of the soundings here, and certain of our shallow soundings between the South Sandwich Islands and the South Orkneys have been plotted. The wide shelf to the south and east of the latter group of islands is also well defined. The complicated form of the link between Coronation Island (South Orkneys) and Clarence Island is extremely well shown for the small scale used, as is also the trough which extends through the Bransfield Strait to a position south of Clarence Island.

The third recent bathymetric chart is U.S. Chart No. 2562 produced by the United States Hydrographic Office in 1943. This map, which comprises a wide area around the Antarctic Continent, is contoured in fathoms; it is not, therefore, so easily compared either with our own chart or with those of Stocks and the Commonwealth of Australia. There are, however, certain discrepancies in the Scotia Sea area (some of which are referred to in a brief review by Hinks & Mackintosh, 1943), and these should be mentioned here, since it would appear that some of the data available have been overlooked. Perhaps the most important discrepancy is in the representation of the South Sandwich Trench, where the deep water at the north-western extremity is shown as lying mainly south of latitude 55° S with a pronounced south-westerly trend, and where also the width at the southern end is given as some 60 miles between the 3500 fm. (6401 m.) contours. Between the 3000 fm. (5487 m.) contours in the same latitude the width of the Trench is shown as approximately 80 miles. Both these widths are far in excess of either our own or the Australian interpretation of the data then available. In the neighbourhood of the South Orkneys the Bart Bank (in approximately 61° S, 41° 20′ W) is shown as part of the ridge connecting these islands with the South Sandwich Group, but, if reference is made to British Admiralty Chart No. 3176, the soundings there shown give little indication that this bank is connected with the South Orkney shelf. In view of the previous evidence of multiple folding in the various sectors of the Arc it is, in our opinion, more probable that this is an isolated bank or part of a bank, which lies in an east and west direction and which is parallel to the main

ridge.[1] Farther to the west the complexity of the ridge connecting the South Orkneys with Clarence Island is not very clearly shown, and a ridge, the existence of which must be regarded as doubtful, is shown as running north-west for some 220 miles from Elephant Island; our soundings here do show a small area less than 2000 m. in depth some 75 miles from Elephant Island in the same direction, but there appears to be little evidence in support of the connexion of this area with the island. In the Bransfield Strait the outline of the comparatively deep basin is not well shown. In part this may be due to the small scale of the chart but it would also appear that the compilers have overlooked the data published in pl. xlvii of our previous report.

Certain banks shown on this chart are referred to as 'seamounts', a term which does not appear to have been among those considered by the International Committee of 1936 (see p. 60). It appears, however, in the terminology of submarine topography given by Sverdrup, Johnson & Fleming (1942, p. 25), where a 'seamount' is described as 'an isolated mountain-like structure rising from the ocean bottom'. In the present report the original term 'bank' has been retained for all such features.

## DETAILED ANALYSIS OF THE SECTORS OF THE SCOTIA ARC

### TIERRA DEL FUEGO TO THE SHAG ROCKS

In pl. xlv in our previous report the contours of the Arc were drawn to fit as well as possible the data then available. These contours need considerable modification in the light of subsequent soundings, and it therefore seems worth while to examine the various sectors of the Arc as before in some detail.

Very many more soundings have been taken in the vicinity of the Burdwood Bank, which is an accepted feature of the Arc, with the result that the area of the bank, of less than 250 m. (137 fm.) in depth, has been considerably reduced. Six lines of soundings were run across the bank between 1932 and 1938, one at the western end, two in the middle and three, in a southerly direction from Cape Pembroke, at the eastern end. A series of soundings, crossing the north-west corner of the bank, was also taken in 1936, in 54° S, as part of a line of soundings from South America to South Georgia. A further line, approximately south-east by south from Cape Pembroke, was of great value in the determination of the eastern limits. North of the bank these various lines have proved beyond doubt that there is relatively deep water between the bank and the Falkland-Patagonian shelf. A large area with depths greater than 500 m. (273 fm.) is found here and extends considerably west of the longitude of the Falklands. Depths of more than 1000 m. (547 fm.) extend along almost the whole northern side of the bank, the western limit of the contour being in, approximately, 60° 15′ W. The 2000 m. (1094 fm.) contour can now be shown to lie in about 58° 45′ W and a corresponding alteration in the 3000 m. (1641 fm.) contour can also be made in view of this fresh evidence.

The separation of the Burdwood Bank from the continental shelf would now appear to be firmly established and the profile running south from Cape Pembroke across the Scotia Sea, which we have

[1] The soundings taken by the 'Walter Rau' and already mentioned in the footnote to p. 66 indicate that there is some doubt about the existence of the Bart Bank, at any rate in the position at present assigned to it. The information available from Stocks's map shows that the 'Walter Rau' obtained at least three soundings exceeding 3000 m. (1641 fm.) at or near the position of the bank, and what is perhaps more important, obtained further deep soundings between here and the Orkney shelf. This latter evidence strongly supports our contention that if the Bart Bank does exist at or near the position now shown for it, then it must be an isolated feature.

There is little information about this bank. It first appeared on British Admiralty Chart No.3176 in 1941 and the authority for its insertion was a Norwegian chart dated 1938 (private communication to the author from the Hydrographic Department of the Admiralty). The only other references to the bank which can be found appear to be on U.S. Chart No. 2562 (referred to above) and a very brief statement in the *U.S. Sailing Directions for Antarctica*, 1943 (p. 259) of the position and depths found. No authority is quoted in support of this information.

already shown (Text-fig. 12*d*), illustrates clearly the gradual descent of the continental slope from the Falkland Islands to a depth of slightly over 3000 m., the comparatively sharp rise to the bank itself and the fairly steep slope away to an irregular bottom at an average depth of 4500 m. (2461 fm.). South of the bank the contours as now drawn show that the slope is steeper than was supposed, though the average gradient as determined from five crossings is not more than $3\frac{3}{4}°$. Several good continuous records were obtained here with the 'Acadia' recorder and from these it can clearly be seen that one of the most prominent features is the considerable irregularity of the bottom down the slope. This is, perhaps, most clearly seen at depths of less than 3000 m. (1641 fm.). As we have already mentioned, such irregularity of the bottom, just south of the connecting link, appears to be a well-marked feature of this sector of the Arc.

Eastwards towards the Shag Rocks the recent soundings are in close agreement with those determined prior to 1932, and provide confirmation of the suggested line of the connexion. Nine more soundings of less than 1000 m. were obtained between 51° W and 53° W on the line from the Burdwood Bank towards South Georgia with a minimum depth of 581 m. (318 fm.). Farther to the east a series of soundings between South Georgia and the Falkland Islands provides valuable evidence of the extensions westward of depths of less than 2000 m. (1094 fm.), to a position in approximately 53° S, 46° 40′ W, and a formerly isolated sounding of less than 2000 m. is now linked up with the Shag Rocks, some 170 miles to the east.

The soundings obtained on this east and west line have been corroborated by five lines of soundings in a north and south direction, between the meridians of 43° W and 46° W. Agreement with the previous results was again very good. As will be seen from Pl. XXIII two of the lines in this series were run in weather which allowed soundings to be taken at intervals of 30 min. (except for one gap) or approximately every $4\frac{1}{2}$ miles, and there can be little possibility that any outstanding feature of the bottom was missed in this region.

Immediately south of the Arc, between 44° W and 45° W, and in the latitude of approximately 54° 30′ S, there is an interesting deep fold, some 50 miles in length as at present known, where two depths of more than 5000 m. were obtained. The western end was determined by the 'Meteor' in 1926 and was shown on our original chart as an isolated deep sounding. In November 1932 a line of soundings on a southerly course crossed this fold about 25 miles to the east of the position of the 'Meteor' sounding. No sounding of more than 5000 m. was obtained, but four depths, ranging between 4879 m. (2668 fm.) and 4998 m. (2733 fm.) were determined over a distance of 7 miles between the latitudes of 54° 30′ S and 54° 37′ S, in the longitude of 44° 36′ W. This narrow trench is followed by a sharp rise to a sounding of 2776 m. (1518 fm.) in a distance of $4\frac{1}{2}$ miles; equivalent, roughly, to a slope of 15°. This is considerably steeper than the slopes normally found far from land. It is based on only two soundings, and thus, although the angle cannot be less than 15°, the recorder might well show parts of it to be steeper, especially if the ship moved at right angles to the contours. This further proof of parallel folding adjacent to the main ridge must be regarded as strong support for the theory of the arcuate connexion.

In April 1934 the 'Discovery II' obtained a single sounding of 5088 m. (2782 fm.) at St. 1335 (54° 37·8′ S, 44° 12·6′ W) to the east of the previous line. Later, unfavourable weather prevented us from obtaining soundings on a line which crossed the fold from south to north, in approximately 45° 30′ W, at a point where the soundings of the 'Meteor' suggest an extension of the fold to the west.

In the immediate vicinity of the Shag Rocks the recent soundings show that the 500 m. (273 fm.) contour to the west of the Rocks should extend some 25 miles farther to the west; and the limit of the 1000 m. (547 fm.) contour in the same direction can now be determined with fair accuracy.

There still remains the gap in the Arc between the meridians of 48° W and 49° W. It is now seen that the width of this is considerably less than hitherto shown, though from the evidence of the soundings alone its existence must be considered as certain. Hydrological observations do not either confirm or deny its presence, although there is some slight evidence that a northward movement of cold bottom water may occur at this point. Soundings, however, show the gap to be connected with a narrow trough of moderately deep water which lies east and west, between the Arc proper and a parallel ridge to the north. This parallel ridge, which extends east from the Falkland Islands for some 600 miles, at depths less than 3000 m. (1641 fm.), and which has an area of 5000 sq. miles less than 2000 m. (1094 fm.) in depth at its eastern end, is an interesting feature. It extends east to the longitude of 41° 30′ W and there can be no doubt that from this position to some distance west of the Falkland Islands it is completely separated over its whole extent from the main line of the Arc. The trough which constitutes the separation is narrow, but for the greater part of its length is more than 3000 m. (1641 fm.) in depth. It can finally be traced, by the 500 m. (273 fm.) depth contour, to approximately 53° 30′ S, 63° 30′ W; about 150 miles west of the mean longitude of the Falkland Islands.

The soundings shown on our original bathymetric chart gave a strong indication that such a trough existed, although the extent of the northern ridge, as determined by the 3000 m. (1641 fm.) contour, was shown only to the longitude of 47° W. Our more recent soundings in this area, however, comprise two lines between the Falkland Islands and South Georgia, five lines in a north and south direction, and four on north-westerly and south-easterly courses. All these series of soundings cross this trough, and four of the north and south lines and three of the others crossed completely the eastern end of the Falkland Ridge. The area less than 2000 m. (1904 fm.) in depth, of which only the southern part is shown on our present bathymetric chart (Pl. XXIII), was thus fairly extensively sounded out and its limits determined with reasonable accuracy.

Geologically, this ridge parallel to the Scotia Arc raises some interesting questions. For example, the structure of the Falkland Islands bears not the least resemblance to any structure so far determined in the various sectors of the Arc, and yet there can be no doubt of the connexion between the Falkland Islands and the comparatively shallow area which lies some 500 miles farther east, thus forming a parallel fold, such as is symptomatic of the Arc in general. It is not, perhaps, within the scope of this report to discuss these implications, but it should be noted that soundings provide evidence of rather similar conditions north-east from South Georgia, fuller details of which will be given when we consider the soundings in that area.

## SOUTH GEORGIA AND THE SHAG ROCKS

Soundings taken since 1932 immediately to the west of the Shag Rocks have already been mentioned, their effect on the contours here being quite marked; but new soundings north and south close to the Rocks, and eastwards to South Georgia, cause little alteration in our original conception of the contours in this area. Two lines of soundings, however, which crossed this part of the ridge in a north-easterly direction, enable us to complete the 2000 m. contour south of the ridge, which had been in doubt; but the new contour follows closely the original tentative line. South of the Shag Rocks the 3000 m. contour is found to lie some miles north of the line previously shown, thus reducing the width of the ridge to a considerable extent.

Our soundings clearly show that the Shag Rocks constitute an important link in the Scotia Arc; and it is of considerable interest to find geological evidence in support of this in Tyrrell's recent report (1945). Stones dredged from a depth of 199 m. (109 fm.) at St. 474 (1 mile west of the Shag Rocks) showed a preponderance of greenstones which, from a close examination, Tyrrell considers to be

'congruous with the whole assemblage of rock types found in the Scotia Arc'. They are, in fact, very similar to specimens from Tierra del Fuego and Clarence Island.

Recent work close around South Georgia itself has caused only minor alterations in our previous delineation of the contours of the shelf surrounding the island. On the other hand, offshore soundings beyond this shelf have been of some interest, especially in a north-easterly direction. Here we have found a considerable area, probably of not less than 2500 sq. miles, which is centred about 180 miles from land and where a number of soundings of less than 2000 m. (1094 fm.) have been obtained. The minimum depth determined here so far is 887 fm. (1622 m.), in approximately 53° 04′ S, 33° 27½′ W. Altogether, eleven soundings of less than 2000 m. were obtained from two lines across this bank, which for convenience of identification we shall refer to as the North-Eastern Bank.

Directly north of Cape Crewe is another but considerably smaller area of less than 2000 m. in depth, which was shown on our original chart. Recent soundings here do not materially alter the position of the contours, and the connexion of this bank with the shelf around the island remains almost as originally shown.

The American bathymetric chart previously mentioned is in near agreement with our conception of the connexion of this latter bank with South Georgia, but the North-Eastern Bank is shown as a major feature in a ridge termed the 'South Sandwich Swell', stretching away from South Georgia in a north-easterly direction for some 700 miles. We have not, as yet, been able closely to examine all our oceanic soundings in this area, but it does not appear likely that this ridge exists as shown in the American chart, and the North-Eastern Bank is certainly not connected to South Georgia at a depth less than 1500 fm. (2743 m.); our many soundings between this bank and the island show that depths of more than 3000 m. (1641 fm.) are found here over a wide area. It seems much more probable that the North-Eastern Bank is part of a ridge concentric with the loop of the Scotia Arc, a ridge which also includes the small area of depths less than 3000 m. (1641 fm.) immediately to the east of the bank, together with another recently discovered bank in a position centred approximately on 52° 45′ S, 24° 30′ W. This latter bank was only crossed once (October 1936) and the minimum sounding was 1012 fm. (1851 m.) in 54° 41′ 48″ S, 24° 09′ 54″ W. It is possible that this ridge is continued to the south and east, linking up with the depths of less than 4000 m. (2187 fm.) shown there in approximately the latitude of 55° S; and it may even connect with the shallower area far to the south again, in a position centred approximately on 60° S, 20° W. We have drawn the 4000 m. and 3000 m. contours to conform with this suggestion in so far as the banks to the north-east of South Georgia are concerned but, in the absence of intermediate soundings between the various banks, this interpretation must remain largely hypothetical.

If our theory is correct then, in view of the known structure of the Arc in general, and especially of the prevalence of folds parallel to the main line, it appears that the shallower depths farther again to the north-east (in approximately 50° S, 33° W, and from thence to approximately 47½° S, 37° W) will not be connected to the North-Eastern Bank but form a further small fold also concentric with the Arc proper. Much more work will be necessary before this point can be settled, but there remains no doubt that the main line of the Arc lies as we originally suggested, and not through a parallel ridge either north or south of South Georgia.

## SOUTH GEORGIA TO THE SOUTH SANDWICH ISLANDS

The link between South Georgia and the Clerke Rocks was firmly established by our soundings prior to 1932, but the evidence in support of a connexion between the Rocks and the South Sandwich Group was not entirely satisfactory. Unfortunately our recent work does not provide much additional information. It can be seen in Pl. XXIII that although several new lines of soundings were taken in

this area, there is still a gap in the ridge between 30° and 31° 20′ W. However, there is still room in this gap for further soundings to reveal better evidence of a connecting ridge. Apart from this the following facts may be cited in general support of the connexion between South Georgia and the South Sandwich Islands.

(*a*) The profiles drawn in Text-figs. 12*b* and *c* show the typical irregularity of the bottom immediately south of the least depths (i.e. on the inner side of the loop), which is so marked in the Burdwood Bank-South Georgia sector of the Arc.

(*b*) The area of less than 3000 m. (1641 fm.) centred about 32° W, with its revised and more elongated outline (from west to east), may represent a crest on the ridge.

(*c*) A number of new soundings show that the northern end of the South Sandwich Trench extends westwards as far as 33° 37′ 48″ W (see Pl. XXIII). Since elsewhere the Trench is parallel to and outside the Arc, it may be supposed that part of the ridge lies just south of this westward extension of the 5000 m. (2734 fm.) contour.

Our original bathymetric chart showed the extension of the ridge on which the South Sandwich Group is situated as running roughly north from Zavodovski Island and then to the west. In late November 1932, soundings on a course approximately north-west from this island located a shallow bank some 35 miles away from land. The minimum depth determined was 174 fm. (318 m.) and altogether six soundings of less than 1000 m. (547 fm.) were obtained; four of these being less than 500 m. (273 fm.). Although this bank is close to the South Sandwich Group and therefore should, perhaps, be considered as part of the island ridge, we might also suggest that by its position and depth it is strong evidence of the trend of the connexion towards the Clerke Rocks and South Georgia.

## SOUTH SANDWICH ISLANDS TO THE SOUTH ORKNEY ISLANDS

In Pl. XXIII several new lines of soundings can be seen on, or crossing, the ridge connecting the islands of the South Sandwich Group, and these give a much more accurate representation of the general outline of the ridge, certainly on the western side. Here it will be seen that the 3000 m. (1641 fm.) contour lies, in general, much closer to the islands than we had hitherto supposed and that the depths less than 2000 m. (1094 fm.) have been more precisely determined. In our previous chart the six southern islands (Saunders, Montagu, Bristol, and the Thule group—see Text-fig. 14) were shown as being connected by a ridge at a depth of less than 2000 m. (1094 fm.), but this has now been found to be incorrect. The saddle depth of the ridge between Montagu and Saunders Islands is now found to be greater than 2000 m., the least depth obtained being 1354 fm. (2476 m.), and although, so far as is known, no soundings have yet been taken between Montagu and Bristol Islands, similar conditions may well be found to exist here. The rise of the bottom to the saddle depth between Montagu and Saunders Islands, or between Saunders and Candlemas Islands is, however, almost 1000 m. (547 fm.), and is in itself sufficient evidence of the connecting ridge.

To the east of the South Sandwich Islands we have not gained so much information, except in the vicinity of Saunders Island, where the 3000 m. (1641 fm.) contour can now be placed with some accuracy. The two crossings farther south show a wider shelf at depths of less than 2000 m. (1094 fm.), with a consequent displacement of the deeper contours.

It will thus be seen that the connexion through the South Sandwich Group falls into three well-marked areas. At the northern end there is a comparatively shallow submarine plateau surrounding the islands, which stretches away in a north-westerly direction towards South Georgia. In the centre we have Saunders Island, Montagu Island and, probably, Bristol Island, rising from slightly greater depths. At this point also, the width of the ridge narrows considerably, the least distance between the 3000 m. contours being about mid-way between Candlemas and Saunders Islands. South of this the

ridge again widens and becomes more pronounced, the distance between the 3000 m. contours being approximately 100 miles, as compared with the width of 25 miles at the narrowest part.

We now come to the most important results of our recent sounding work in the area of the Scotia Sea and Arc; that is, the determination of some 200 miles of the connexion which we believe to exist between the South Sandwich Islands and the South Orkneys. Prior to November 1932, the largest scale British Admiralty chart for this area showed only three soundings of less than 2000 m. (1094 fm.). Early in that year, however, the 'Discovery II' had obtained a good line of soundings across the ridge in 36° W, with a least depth of 297 fm. (543 m.), and this was shown in our previous chart. For a large part of the year this region is covered by pack-ice, and it is unfortunate that in subsequent years the ship was not able to be there in the late summer when open water may be expected. The ridge is thus still inadequately explored, but one new line of soundings was obtained in November 1932, when the ice was farther south than usual for that month (see Mackintosh & Herdman, 1940, pl. lxix), and this can be seen in Pl. XXIII as an irregular line running from the South Orkney towards the South Sandwich Islands. The line is irregular because the ship was skirting the pack-ice throughout the passage. It would at any time be difficult to lay a course between the South Orkney and South Sandwich Islands which would include soundings on unknown parts of the ridge, but it happens that the course determined for us by the pack-ice resulted in some very informative soundings, especially between the meridians of 38° and 32° W. Here four well-marked areas of less than 1000 m. (547 fm.) in depth were found and in two of these the minimum depth was less than 500 m. (273 fm.).

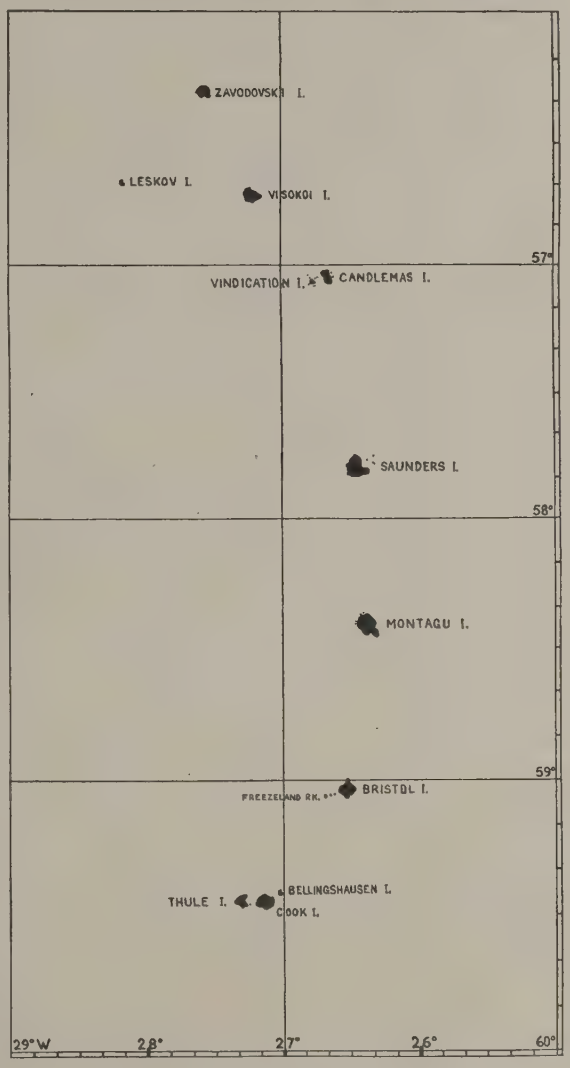


Fig. 14. The South Sandwich Islands.

This line first ran south from the South Orkneys to the ice-edge in the latitude of 61° 57′ S, and then turned to the east to follow the ice-edge. The soundings obtained on the southerly run, together with those at the beginning of the easterly course, show a remarkable extension of the South Orkney shelf to the south and east.[1] The first part of the eastward course must have lain south of any main connecting ridge, for it was not until the ship turned almost north in 37½° W that the first bank was located. Here six depths of less than 1000 m. (547 fm.) were determined and of these one was less than

[1] Soundings taken here by the 'Walter Rau' have already been mentioned in the footnote to p. 66 and they confirm this extension of the South Orkney shelf. Stocks's map, however, is on a comparatively small scale and it is probable that the soundings attributed to the 'Walter Rau' represent only a fraction of those taken. Nevertheless, of those plotted, there are 25 of less than 2000 m. (1094 fm.) and 20 of less than 1000 m. (547 fm.). They are in close agreement with our soundings and although it is not now possible to include them in our bathymetric chart (Pl. XXIII) their inclusion would have caused only local variations in the general trend of the contours shown for the South Orkney shelf.

500 m. (273 fm.); the minimum sounding was 373 m. (204 fm.) in 60° 53′ S, 37° 13′ W. Continuing to the north-east for a distance of about 35 miles the line of soundings then crossed the bank found on the northerly run earlier in the year. Agreement with the previous results was good and it was found that the hitherto isolated depth of 543 m. (297 fm.) could be linked up with a larger area. Four depths of less than 1000 m. (547 fm.) were determined on this north-east line and these included one of 488 m. (267 fm.), in 60° 17′ S, 35° 48′ W, roughly 9 miles east-by-north of the earlier sounding of less than 500 m.

From here the course still lay to the north-east, to the longitude of 35° 20′ W, where it became possible to turn east. Shortly after turning, and about 20 miles from the previous bank, another area with depths less than 1000 m. (547 fm.) was located. In all, seventeen soundings were obtained here and the minimum depth was 667 m. (365 fm.), in 62° 02·5′ S, 34° 41′ W. A number of these soundings were taken in a small area at the extreme eastern end of this bank, but it has not been possible to show all of them owing to the small scale of our bathymetric chart.

Not much farther to the east more shallow soundings were met with. Here ten depths of less than 1000 m. (547 fm.) were obtained over a distance of about 40 miles, the least being 602 m. (329 fm.), in 60° 00·5′ S, 32° 30′ W.

Between these last two shallow areas there exists a small gap, to which we have already referred in our general discussion on the Scotia Arc. Only one sounding of more than 3000 m. was obtained here (3807 m. (2082 fm.)), in 60° 03·5′ S, 33° 33′ W; the three remaining depths in the gap were approximately 1000 m. less.

The traverse of the ridge continued east from the 40-mile bank for about 30 miles. Unfortunately, the ice began to trend in a northerly direction here and we were thus prevented from obtaining soundings over the remaining distance of 110 miles to Southern Thule. The line now was directed in general to the north-east, towards Montagu Island, but the soundings obtained were of considerable value in the determination of the 3000 m. contour.

There still remains a wide area east of the South Orkney shelf where, so far as we are aware, no soundings have yet been obtained,[1] and there is also the gap to the west of Southern Thule. However, despite the lack of evidence from soundings in these areas, there can now be little doubt that the banks discovered in 1932 form part of a well-marked connexion between the South Sandwich Islands and the South Orkneys. Further evidence is provided by the indications of considerable folding at the western end of the portion of the ridge just described. Here, between the meridians 36° W and 38° W, is a complicated bottom of varying depths, such as is a common feature in other parts of the Arc. Steep slopes are prevalent and we have one instance, in approximately 61° 10′ S, 35° 03′ W, where a slope of 13° occurred between two soundings nearly 7 miles apart.

## SOUTH ORKNEYS TO CLARENCE ISLAND AND THE SOUTH SHETLANDS

In our earlier report we stated that from the geological evidence then available the South Orkney Islands did not appear to form an integral part of the Scotia Arc, although soundings indicated that they were almost certainly a link in the chain. In January 1933 the 'Discovery II' made a running survey of the islands, and in the course of the work rock samples were collected from seven localities (Sts. 1089–1095) widely distributed among the group. These specimens were examined by Tilley (1935), who reported that in their general relationships they bear a striking similarity to rocks from the South Shetlands.

[1] Three soundings of less than 2000 m. (1094 fm.) were obtained by the 'Walter Rau' between 60° 15′ and 60° 25′ S, and in 39° to 39° 30′ W, which suggest that the 2000 m. (1094 fm.) contour on the northern side of the ridge should lie considerably north of the tentative line we have proposed in Pl. XXIII. The depths concerned are given as 1700, 1700 and 1800 m. (930, 930 and 985 fm.).

The connexion of the South Orkneys with Clarence Island was presumed before 1932, and we have now presented evidence from soundings which strongly supports the theory of a direct connexion between the South Orkneys and the South Sandwich Group. That the connexion is not likely to lie north of the former islands can be seen from Pl. XXIII; here we find more evidence of the folding which, inside the loop of the Arc, appears as a prominent feature of the bottom west of the meridian of 40° W. About 30 miles north and west of Laurie Island (the most westerly of the Orkney Group) is found the deepest area yet determined within the Arc; more than twenty soundings greater than 5000 m. (2734 fm.) have been obtained here by the 'Discovery II', the maximum depth being 5548 m. (3034 fm.) in 60° 16′ S, 43° 26′ W. It is also possible that this deep water extends farther to the west than is at present shown.

On the southern side of this trench the slopes are comparatively steep; one line of soundings in the longitude of 44° 30′ W gives an average slope of 16°, which is only 4° less than the very steep slope away to deep water immediately north of Coronation Island (the largest of the Orkney Islands) (see p. 66). To the north of the trench the bottom rises quite gradually to an extensive bank of depths less than 2000 m. (1094 fm.), which appears to be roughly circular in shape, with a diameter of about 45 miles. To the east this bank cannot extend beyond the limit now shown but it is possible that there may be a slight extension to the west. This, however, cannot be more than 20 miles as there is a well-sounded deeper area, of more than 4000 m. (2187 fm.), between the bank and the nearest depths of less than 2000 m. (1094 fm.) to the west.

The least depth obtained during our two crossings of this Orkney Bank was 1185 m. (648 fm.) in 59° 02·2′ S, 44° 33′ W. Altogether, nineteen soundings of less than 2000 m. were obtained.

These facts, together with the new geological evidence, provide almost certain proof that the South Orkney Islands are included in the main line of the Scotia Arc.

We suggested, in 1932, that the extension of the Arc westwards from the South Orkneys might be found to consist of two parallel submarine ridges, and this assumption now appears to be correct. From the evidence then available we also inferred that the main ridge lay between Coronation Island and Clarence Island. However, the many new soundings now available (especially east and south of the line of connexion) make it almost certain that it is the southern fold which represents the main line of the Arc, and that it connects the South Orkneys direct with the Trinity Peninsula of Graham Land. The northern ridge, which comprises the South Shetland Islands, Elephant Island and Clarence Island lies close to the main connexion, but at its eastern end fades out into deep water at the meridian of 48° W. In the light of our recent work it also appears more likely that the two areas of over 5000 m. (2734 fm.) in depth, which lie between the folds, are part of a continuous trough separating these folds; they are shown thus connected on our present chart. The scale of this chart is small and all our soundings in this area cannot be shown; we have, therefore, reproduced the South Orkney-Clarence Island sector of the Arc on a scale which permits the insertion of all our soundings. This is shown in Text-fig. 15, p. 76. The northern slope in the easternmost of the small 5000 m. trenches shown in this figure is, perhaps, the steepest we have met. In approximately 61° 12′ S, 48° W the depth altered abruptly from 1051 fm. (1922 m.) to 2874 fm. (5256 m.) in a distance of 3·8 miles. This is equivalent to an angle of slope of approximately 40°. The deepest sounding obtained here was 3111 fm. (5689 m.), about 8 miles to the north-west of the depth of 2874 fm.

Previously we described the South Orkney-Clarence Island sector as the last oceanic link in the chain of the Scotia Arc, but it now becomes evident that we must consider as a whole the soundings between the South Orkneys, the South Shetlands and Trinity Peninsula, together with the soundings north of the South Shetlands.

Fifty miles north of these islands we again have evidence of folding. Two soundings of more than

5000 m. (2734 fm.) were obtained here by the 'Discovery II' and it is probable that these are connected by a small trench. Forty-five miles approximately west-by-south of this is another small area where depths of more than 5000 m. were obtained by the 'Meteor' in 1926. The area between these soundings and those taken by us is completely unsounded and it is reasonable to suppose that further observations will show that a long but narrow trench extends over the whole distance. North of our 5000 m. soundings is a small bank, with depths of less than 2000 m. (1094 fm.). In fact, this area is very similar in structure to the area north of the South Orkney Islands, except that the slope from the deep water here appears to be slight but regular and the shelf to the north of the South Shetlands is fairly wide.

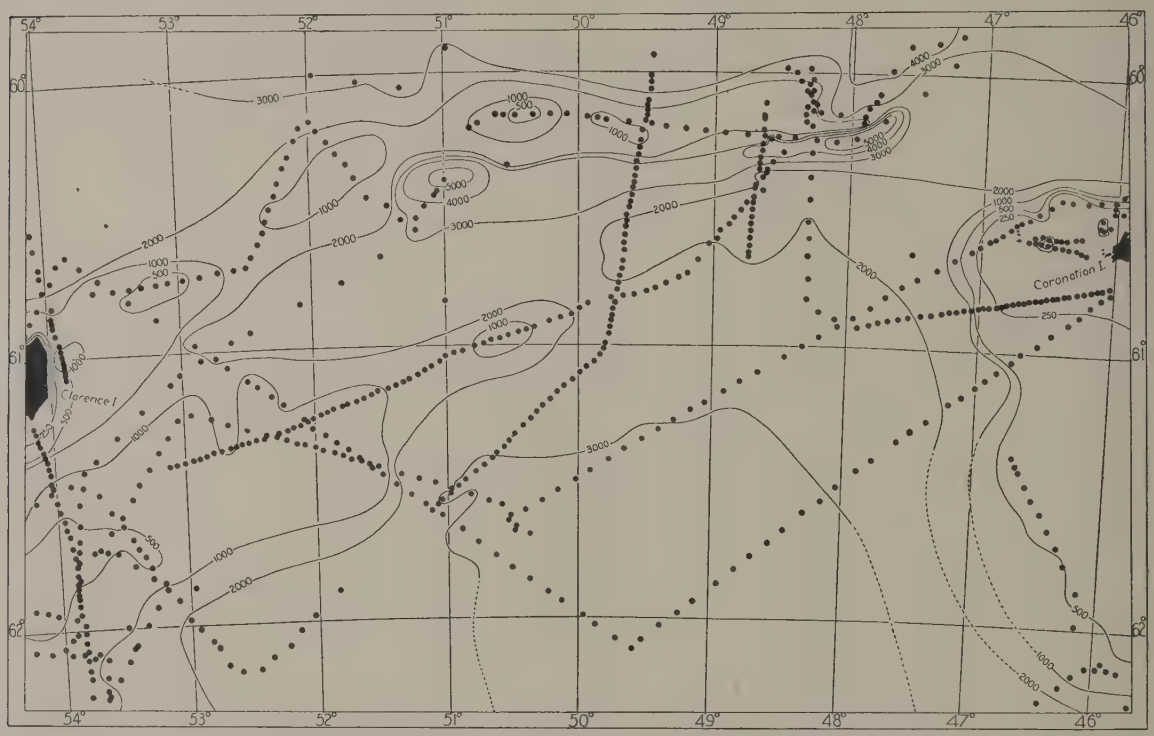


Fig. 15. The Scotia Arc. Positions of soundings and contours of the bottom for the section of the Arc between the South Orkneys and Clarence Island.

Between King George Island and Elephant Island information is scanty, but such evidence as is available no longer supports our original conception of a connexion here at depths of less than 250 m. (137 fm.); it now appears more likely that the average depth of water on the ridge is less than 500 m. (273 fm.), with a small bank of less than 250 m. in the centre. To the north of Elephant Island one line of soundings, however, showed that the rise from 1872 fm. (3423 m.) to 151 fm. (276 m.) was at an angle of approximately 13°.

If we now consider the contours of the Bransfield Strait in conjunction with those of the bottom west of Clarence Island it will be found that the deeper water of the strait can be traced, by means of the 1000 m. (547 fm.) contours, to a position to the north of Coronation Island, South Orkneys. Admittedly, the trough south of Clarence Island is very narrow, but there can be little doubt that it exists. The average depth of water on the ridge south of the trough is less than 1000 m. for a large part of its length; it seldom exceeds 2000 m. (1094 fm.) in depth and there is an extensive area south of Clarence Island where the soundings are less than 500 m. (273 fm.). The least depth determined by us on this

southern ridge was 305 m. (167 fm.) in 61° 36′ S, 53° 35′ W. In the Bransfield Strait many new soundings have made little difference in the general outlines of the bottom, but in our present bathymetric chart (Pl. XXIV) we have introduced a contour at 1500 m. (820 fm.) in order to show more clearly the deeper parts of the basin south of King George Island and south of Gibbs Island. It is now apparent that the width of the trough south of Bridgeman Island is much less than we had hitherto supposed, but there is no doubt of the continuity of the basin at depths between 1000 and 1500 m.

On the northern side of the Strait it will now be seen that the 250 m. (137 fm.) contour enters all the bays and straits on the southern side of the South Shetland Islands; in two instances, depths of more than 500 m. (273 fm.) occur just inside the entrance to a strait. Short slopes of considerable magnitude exist off this side of the islands, and details of some of these will be given when we consider the application of our soundings to the various surveys carried out by the 'Discovery II'.

Unfortunately we still lack evidence from soundings whether Bridgeman Island is connected with King George Island (see Herdman, 1932, p. 230). Such further soundings as have been obtained add but little to our previous knowledge, but in view of the opinion given by Tyrrell (1945), that from its geological structure Bridgeman Island may be considered to be an island of the South Shetland Group, we have now shown the 500 m. (273 fm.) contour as running south of this island.

## SOUNDINGS DURING HYDROGRAPHICAL SURVEYS

The 'Discovery II' has been engaged mainly in oceanographical work, and little time could be allotted to hydrographic survey. Usually about a month in each commission was available for surveying in the Dependencies of the Falkland Islands, and it was often possible to spend a few days in such work elsewhere when opportunities arose. In the Dependencies it was decided that the method of 'running survey' would be most suitable having regard to the time available, the imperfection of existing charts, and the great extent of the coastline in the Dependencies. By this method a skilled navigator can obtain excellent results, and much ground can be covered in a short time.

The immense value of echo sounding during this type of work was clearly demonstrated during the running survey of the South Sandwich Islands by the 'Discovery II' in 1930. A full description of this survey has already been given by Kemp & Nelson (1931). In subsequent years the 'Discovery II' carried out a complete running survey of the South Orkney Islands and made very considerable progress with a survey of the South Shetland Islands by the same method—work which could not have been attempted without continuous echo soundings, on account of the numerous off-shore dangers common to nearly all islands in this part of the world.

At the time of the South Sandwich and the main South Orkneys surveys the 'Discovery II' was fitted only with 'listening' type echo-sounding equipment, with which the maintenance of a proper sounding routine entailed long hours of tiring work. Although some preliminary work had been done in 1929–30 the main South Shetlands Survey was not begun until December 1934, by which time the automatic recorder had been fitted to the deep-water set. Shallow soundings during this season still required the use of the 'listening' gear, but its use could be restricted to the minimum necessary for entering or leaving an anchorage or when shoal water was met with on passage round the islands. When the survey of the South Shetlands was continued in December 1936 both deep and shallow echo-sounding sets were fully automatic.

Since the fitting of the deep-water recorder other running surveys carried out by the 'Discovery II' include work on the three northernmost of the Balleny Islands (in 1936 and 1938), the examination of the neighbourhood of Tristan da Cunha and various passages through the lesser known channels of Magellan Strait. Many little known or imperfectly surveyed Antarctic and sub-Antarctic islands were

circumnavigated and depths approaching the Antarctic continent were determined, in March 1939, in the meridian of Greenwich, when it was also possible to make a rough survey of the ice barrier and coastline between this meridian and that of 4° E. Additions were also made to our previous work around South Georgia. The lines of soundings in the Ross Sea in 1936, and between 1936 and 1939 across the Discovery Bank (in approximately 42° S, 1° E) cannot, perhaps, be classed strictly as hydrographic surveys; reference to this work is made in a later section.

For the purpose of this report it is not necessary to describe the various surveys in their full detail. A short account of the work in each of the more important regions will, perhaps, suffice to give some idea of the value of echo sounding at these times.

## SOUTH ORKNEYS SURVEY

A very complete account of the running survey of 1933 and of the preliminary work leading up to it has been given by Marr (1935). The 'Discovery' made a short visit to Signy Island in 1927, and in 1931 the 'Discovery II' made some observations on the west and north sides of Coronation Island. The principal survey was undertaken by the latter ship in a period of 28 days beginning on 2 January 1933, during which about 2250 soundings were made, mostly with the Pattern 751 'listening' type shallow-water set. Later on the 'Discovery II' made two further short visits in April 1934 and February 1937. On this last occasion (which was subsequent to the publication of Marr's report) the south coasts of the islands were free from ice and in the nine days available much was done towards the completion of the survey. Continuous soundings were taken with both recorders, and records representing some 41 hours of steaming (or, approximately, 240 miles) were obtained. The various tracks of the ship during this period of continuous sounding are shown in Text-fig. 3*c*, p. 46. Each record has a number, and reference to Appendix II of this report will provide fuller details.

For further details of the South Orkney surveys reference should be made to Marr. All that need be said here is that the shelf surrounding these islands (where the majority of soundings were taken with the shallow-water set) offers an interesting comparison with that of other islands comprising the Scotia Arc. At South Georgia, for instance, depths on the western side of the island are comparatively shallow over a fairly wide coastal shelf and the bottom is certainly more regular than on the eastern side. Here there are a number of fjords and glaciers, and depths of considerably more than 250 m. (137 fm.) are often found. The coastal shelf is narrower and much more irregular, with a greater mean depth.

Of the various islands comprising the South Sandwich Group only one, Leskov Island, rises sharply from moderate depths. At the remainder there is generally a narrow but shallow coastal shelf, although in certain places where there are signs of comparatively recent volcanic activity, moderately deep water is found close to land. The submarine crater in Douglas Strait, to which we have already made reference, is, perhaps, the most interesting example of these exceptions.

The coastal shelf around the South Orkneys is, perhaps, the most outstanding example of the varying features of these shelves in the whole Arc. The islands themselves are rugged in character and it might well be expected that considerable variations in depth would occur in the various straits and harbours, and off the coasts. With only a few exceptions such conditions are not found. In general the coastal shelf, straits and harbours are shallow, although two small deeper areas exist south-east of Signy Island and north of Larsen Island; the latter has a maximum depth, so far determined, of 348 fm. (636 m.) in a position approximately 1 mile north-east of Melsom Rocks (see British Admiralty Chart No. 1775—in Marr, 1935). On the northern side of the islands the coastal shelf, at depths of less than 250 m. (137 fm.), extends at the most for some 3 or 4 miles and the slopes away to deep water are considerable.

On the southern side of the South Orkneys, however, we find a coastal shelf considerably wider than is usual around the islands in the Arc. The shelf, as determined by the 250 m. (137 fm.) contour, extends for some 15 or 20 miles south of the islands, but it is the extension beyond here of depths between 250 m. (137 fm.) and 500 m. (273 fm.) which is, perhaps, one of the most interesting features in these parts. The 500 m. contour extends south to the latitude of 62° S and, as will be seen from our bathymetric chart (Pl. XXIII) of the Scotia Arc, a wide area is thus included. Furthermore, there is a very gentle slope from here to the 1000 m. (547 fm.) contour, and it is only then that a moderate slope to the greater depths occurs.

The extent of the coastal shelf in relation to the South Shetland Islands, to the survey of which we shall shortly refer, is again different to those already mentioned. To the north of the islands there is a comparatively wide shelf where depths do not exceed 250 m. (137 fm.), but over almost the whole length of the Bransfield Strait moderately deep water is found close to the south of nearly all the islands. In the southern part of the straits which separate the various islands, and in Admiralty and King George Bays, it will be seen (Pl. XXIV) that depths of more than 250 m. (137 fm.) extend in a northerly direction for some distance. In two instances the 500 m. (273 fm.) depth contour enters the Strait and the slopes here are among the steepest we have met. Nearly all the islands appear to be steep-to both on the southern side and in the various straits. Admiralty Bay resembles a fjord and moderately deep water extends almost to its head, but King George Bay is in general much more shallow. The shelf on the northern side of the group is generally flat, and the slopes away to deep water are gentle.

## SOUTH SHETLANDS SURVEY

In 1927 the 'Discovery' carried out some preliminary work on the survey of the South Shetlands, but the number of soundings taken was small. Between December 1930 and March 1931 the 'Discovery II' was working in this area and considerable progress was made with a running survey of Livingston and Snow Islands. A total of 1432 soundings was taken around the western end of the South Shetlands and in the Bransfield Strait, to which reference has already been made in our earlier report (Herdman, 1932). In December 1934 and January 1935 further work by the same ship completed the survey of the islands, with the exception of the eastern half of King George Island. Continuous soundings were taken whenever possible with the 'Acadia' recorder, and the records obtained totalled 140 hours of steaming. The speed of the ship varied considerably with the ever-changing conditions of this survey, but it can safely be said that during this time we recorded soundings continuously over not less than 600 miles of the sea bed. In addition to these soundings the 'listening' type shallow-water set was used when entering or leaving a harbour or anchorage, and as a relief to the deep-water set when it became necessary to clean the hammer or make a small repair. Every effort was made to do this in depths at which the shallow machine could provide an alternative, but breakdowns did not always occur at perhaps the most convenient times. Some 1600 soundings were taken with the shallow-water set during the thirty-one days occupied on the survey.

The remaining work on King George Island was begun in December 1936 and, as before, continued for a month. The weather was bad throughout and it was not possible to finish the survey, although all that remained uncharted was a few miles of the north coast of the island. The part that remains unsurveyed, however, would be difficult of access by ship, even in the best weather. In fact, it may be said that a running survey along the northern coasts of the South Shetlands requires almost perfect weather, and even with this it would be extremely difficult. The shallow-water echo-sounding set was now fully automatic and continuous soundings were thus obtained from both shallow- and deep-water instruments. The records totalled 120 hours of steaming and represent, very approximately,

a survey of not less than 500 miles of the bottom. Owing to the thick weather prevalent this season not all these runs could be used for the survey charts, but although they were not accurate enough for a hydrographic survey certain sounding runs, made on dead reckoning, have been of considerable aid in the construction of our present bathymetric chart of this area. The ship's tracks during the periods of continuous soundings in 1934–5 and 1936–7 will be found in Text-fig. 4, p. 47.

With the exception of Nelson Strait, which is comparatively wide throughout its length, the straits between the islands of the South Shetlands Group are usually narrower at their northern ends. Moderately deep water is found in all the southern entrances, and throughout the straits, but the northern entrances are all shallow. In some instances they are unnavigable even by small ships. Rocks and reefs abound here, and there are strong currents.

In the straits themselves and around the southern coasts of the various islands there is little or no coastal shelf of shallow water, and the slopes up to the land are considerable. In McFarlane Strait, which lies between Livingston and Greenwich Islands, there are depths of more than 500 m. (273 fm.) in the southern entrance, and the 250 m. (137 fm.) contour extends for some 7 or 8 miles towards the northern entrance. Depths of more than 100 fm. (182 m.) were recorded for a further 3 miles in a northerly direction and only in one place, off Yankee Harbour in Greenwich Island, is there any resemblance to a coastal shelf. Here, a shallow shelf, with depths of less than 40 fm. (73 m.), stretches out for about a mile from the harbour entrance, but the slope away from this to the deeper water is considerable. The angle of descent averages from 15 to 18°, with a maximum slope of 26°. Yankee Harbour itself is of interest as, apparently, there is a bar at the entrance, with considerably deeper water in the anchorage.

The southern part of English Strait, which separates Greenwich Island from Roberts Island, is not more than $1\frac{1}{2}$ miles wide, but the width increases towards the centre of the strait before narrowing again for the northern entrance. A narrow trough, more than 250 m. (137 fm.) in depth, runs up the strait almost to the numerous small islands which infest the northern entrance. The coasts of both Greenwich and Roberts Islands fall away sharply into this trough for some miles, but with the widening of the strait into Discovery Bay the deeper water continues north close to Roberts Island. The average slope of the eastern side of this trough appears to be about 14°.

The topography of the bottom of Nelson Strait, which lies between Roberts and Nelson Islands, differs considerably from that of the others. The strait is wide throughout, with a minimum width of $6\frac{1}{2}$ miles, and the coastal shelf on the eastern side of Roberts Island extends for some 3 or 4 miles. The northern entrance, unlike those of the other straits, appears to be remarkably free from dangers, although there are strong currents and some tide-rips. Depths of more than 250 m. (137 fm.) are found on the eastern side of the strait, and this moderately deep trough then curves to the north-west towards the coast of Roberts Island. The western coast of Nelson Island is steep-to, and in a position a few miles south of Harmony Cove there is a small but moderately deep hole with a maximum depth, so far determined, of 324 fm. (593 m.). The slope into this hole from the south-east is approximately $23\frac{1}{2}°$.

With the approaches to Fildes Strait, between Nelson and King George Island, there is a marked change in the character of the bottom topography. South of Nelson Island there is a moderately wide coastal shelf and, although it is penetrated by depths of more than 250 m. (137 fm.) in the approaches to Fildes Strait and in Admiralty and King George Bays, this shelf continues along the whole south coast of King George Island. In the approaches to Fildes Strait, which in itself is only navigable by boats, and that with difficulty, depths of more than 250 m. (137 fm.) extend over a wide area, and are found moderately close to both shores. The slopes here are slight.

Admiralty Bay, in King George Island, reverts more to the character of the straits at the western

end of the South Shetlands and closely resembles a fjord. A trough with depths of more than 250 m. (137 fm.) extends almost to the head of the bay and although the 500 m. (273 fm.) contour along the south coast of the island lies several miles south of the entrance, soundings of more than 500 m. (273 fm.) have been obtained over a distance of 2 miles on a northerly course, just inside the entrance to the bay. The slope down from the coastal shelf at the western side of the entrance is considerable. On a course round Telefon Rocks into the centre of the trough the soundings increased from 35 to 220 fm. (64 to 402 m.) in 0·45 mile; this is equivalent to a slope of 25° and, since it is probable that our course was not at 90° to the line of the contours, the actual slope may well be a few degrees greater.

Farther to the east the 250 m. contour along the southern coast of King George Island swings north towards King George Bay and there appears to be a comparatively narrow trough of this depth extending about a mile into the bay. The slopes, however, are quite gentle and the greater part of the bay appears to be reasonably shallow. Continuing round the coast of King George Island to Cape Melville we find that the coastal shelf, with the exception of a few shallow indentations, remains fairly wide. To the east of King George Island we had assumed (Herdman, 1932) that a ridge with depths of less than 250 m. (137 fm.) existed between this island and Elephant Island (see p. 76). Our more recent work makes this assumption doubtful, and it is now considered more likely that the 250 m. contour swings north about 15 miles east of Cape Melville and then continues round the northern side of the island.

On the northern side of the South Shetlands there is a wide submarine shelf of less than 250 m. (137 fm.) in depth. It is generally quite flat, although the continuous sounding records occasionally show a sharp submarine peak suddenly rising some 150 to 200 ft. from it. One such peak, near Table Island, rose 198 ft. (Record XXX/34) from a level bottom of 57 fm. (104 m.) in less than a minute and normal soundings of more than 50 fm. (91 m.) were again being obtained within $1\frac{1}{4}$ min. As the speed of the ship was $3\frac{1}{2}$ knots this was equivalent to an upward slope of nearly 42°. These peaks, perhaps, are only to be expected, for, in sharp contrast to the southern side of the group, the northern coasts of the South Shetland Islands are infested with small islets and sunken rocks. As we have already stated, navigation is extremely difficult, even in fine weather, and for our running survey it was normally necessary to keep well offshore. The term 'foul', used in many places on the British Admiralty Chart of these regions (No. 3205), is an accurate description of these coasts.

The survey of 1936–7 finished with an examination of Gibbs, Aspland, Eadie and O'Brien Islands, though these are not strictly part of the South Shetland Group. These islands lie in a group about 20 miles south-by-west of Elephant Island, and our survey in February 1937 showed that Aspland, Eadie and O'Brien Islands lie together, in a north and south line, at the western side of the group. Gibbs Island, which is the largest in the group, lies in an east and west direction. Narrow Island, previously shown as a separate island near Gibbs Island, does not appear to exist. It is probable that it has been confused with a low conical hill connected to Gibbs Island by a sand spit some 2 miles in length which runs out in a south-easterly direction. Continuous soundings were taken around Gibbs Island, and close to Aspland Island, for a total of 18 hr. in two days, and these represent a survey of 52 miles of the sea bed (see Text-fig. 5*a*, p. 49). Considerable alterations were made to the previous conception of the outlines of the various islands comprising the group, and the soundings showed that all the islands were steep-to. The slopes, however, were moderate in comparison with those generally recorded in the South Shetlands.

## BALLENY ISLANDS

In the Discovery Committee's programmes hydrographic survey has been concerned mainly with the Dependencies of the Falkland Islands, but when time and conditions permitted every opportunity was taken to examine little known or badly charted land in other regions. Among the most important of these miscellaneous running surveys was that of the three northernmost islands of the Balleny Group. These islands, the more northerly of which is situated in about 66° 35′ S, 162° 30′ E, were, up to 1936, very imperfectly known, and there was considerable doubt about their correct position. They have been sighted on several occasions since their discovery in 1839 but, with the conditions of pack-ice, fog and bad weather which normally obtain here, a close approach was not possible.

In February 1936, while returning from the Ross Sea, the 'Discovery II' found the Balleny Group clear of ice. A running survey was begun and an attempt made to land on Borradaile Island, but with the onset of thick weather it became necessary to abandon both the survey and the attempt to make a landing. There were no signs of improvement in the weather on the following day, and with fuel running low it was essential to continue on passage to Australia. Continuous soundings, however, had been obtained for 8 hr. during the clear weather, representing a distance run of 47 miles, and the tracks of the ship during this period are shown in Text-fig. 3*b*, p. 46.

During the second circumpolar cruise of the 'Discovery II', in 1937–8, a further attempt was made to complete the survey of the Balleny Islands. Approaching the group from the direction of Adélie Land, in January 1938, it was found that the northernmost islands were clear of ice, and as the weather was fine the running survey was resumed at the point where it had been abandoned in 1936. On this occasion the weather remained clear and it was possible to complete the circumnavigation of Young, Borradaile and Buckle Islands. Pack-ice to the southward prevented us from reaching Sturge Island, but the island was clearly visible at a distance of about 17 miles, and it was possible to fix its position approximately with relation to the remainder of the group. As our circumpolar cruise was, of necessity, being worked to a fairly rigid timetable, we were unable to remain at the Balleny Islands for more than two days. In that time, however, the ship covered a distance of 145 miles in 29 hr. of survey, and continuous soundings were taken throughout this period. As with the earlier work the tracks of the ship are shown in Text-fig. 3*b*, p. 46, together with an indication of the likely trend of the more important depth contours.

The Balleny Islands lie approximately in a line from north-west to south-east, and form the crest of a narrow ridge rising abruptly from the southern end of the Macquarie Rise, which connects the Antarctic Continent with Australia.[1] The general level of the bottom near the islands varies between 2500 and 3000 m. (1367 and 1641 fm.), and on the western side the slopes up to the group are considerable. One of our lines of soundings crossed the ridge about $3\frac{1}{2}$ miles north of Young Island, and the angle of slope from the west was $13\frac{1}{2}°$. So far as can be ascertained at present Young Island is steep-to on both sides, and the slopes up to the land from 2000 m. (1094 fm.) correspond in the west to that determined north of the island. To the east the slopes are much less, and from one of 11° at the northern end decrease steadily to 6° off Cape Douglas.

[1] On the U.S. Chart of Antarctica (see p. 67) a possible connexion between New Zealand and the Macquarie Rise is also shown, the link having been based, apparently, on one sounding of 1244 fm. (2275 m.). From a close examination of our lines of soundings in this area and a study of the hydrological data, it is not possible either to confirm or deny the existence of such a link, although the evidence from the soundings would tend to show that this sounding is more likely to be an isolated peak. Deacon (1937, p. 114), in his discussion of the distribution of the bottom water, considers that the hydrological conditions existing in the deep basin of the Tasman Sea may be due either to the basin being shut off by a ridge, or caused by the rugged nature of the bottom topography in this region. On the evidence now available it appears, therefore, that the existence of a connexion between New Zealand and the Macquarie Rise is doubtful.

Buckle Island appears to lie athwart the ridge. At the south-western corner of the island the slope to moderate depths is greater than off Young Island, 17° being the approximate angle, and corresponding to this we find that north of Cape Davis, on the eastern side, the slopes are approximately 12½°. North and east of the island the descent to deeper water appears to be moderate.

No soundings were obtained on a direct line between Borradaile and Buckle Islands, but from the evidence of the line of soundings a few miles to the east it may be suggested that the ridge is continuous between these islands at depths of less than 500 m. (273 fm.). From the soundings obtained south-east of Buckle Island it appears probable that there is also a similar connexion with Sturge Island.

## TRISTAN DA CUNHA GROUP

(Tristan da Cunha 37° 06′ S, 12° 18′ W)

In November 1933 the 'Discovery II' approached Tristan da Cunha from the north. Continuous soundings were taken with the 'Acadia' recorder from 36° 07′ S, 12° 31·5′ W to the anchorage, a distance of 57 miles. At the beginning of the run the bottom was comparatively level at depths varying between 2000 and 2100 fm. (3658 and 3840 m.), and this condition persisted to within a distance of approximately 12 miles from the island. From this point soundings shoaled continuously, though at times with considerable irregularity in the bottom, to a depth of approximately 1650 fm. (3017 m.). The slope now became much steeper, and from a depth of 1079 fm. (1973 m.) the 100 fm. (183 m.) line was reached in a distance of 2·9 miles; equivalent to an average slope of 18½°. A maximum slope of 25° was recorded over a distance of 0·4 miles, between the depths, approximately of 350 and 165 fm. (658 and 302 m.). We have already referred to this slope (p. 54), which was one of the longest over which we were able to obtain continuous soundings, and the profile of the last 33 miles of the approach is shown in Text-fig. 9, p. 55.

On leaving the anchorage our course lay north-west, then west-by-south and, after reaching deep water, approximately south (see Text-fig. 3*a*, p. 46). Continuous soundings were again taken and the run continued to Nightingale Island and thence to Inaccessible Island, a total distance from Tristan da Cunha of 45 miles. West of Tristan da Cunha the 'Discovery II' passed just over 1 mile off-shore and the minimum sounding obtained was 130 fm. (238 m.). Shortly afterwards the depth increased rapidly from 171 fm. (313 m.) to 1044 fm. (1909 m.) and for the next 4 miles the bottom remained very irregular at depths varying between 956 and 1116 fm. (1748 and 2041 m.); there was then a gradual rise towards Nightingale Island, where there is moderately deep water close off-shore. Between Nightingale and Inaccessible Islands the bottom was again very irregular, with a maximum depth of 597 fm. (1092 m.) about mid-way between the two islands. The slope of the bottom in either direction from here was moderately steep.

At Inaccessible Island depths of 100 fm. (183 m.) were obtained at a distance of 2–2·5 miles from the land, both on the run across from Nightingale Island and on the line of departure to the south-west.

Tristan da Cunha, Nightingale and Inaccessible Islands are all steep-to, the two former to a greater degree. At Tristan da Cunha, on the approach from the north, depths of 100 fm. (183 m.) were reached at a distance of 1·7 miles from the land and on the departure to the north-west the edge of this narrow coastal shelf lay at a distance of 1·3 miles off-shore. To the west of the Island, as we have already stated, soundings were over 100 fm. at a distance of 1·15 miles from the land. Littlehales (1932, p. 21) has stated that submarine slopes of 33½° have been found at Tristan da Cunha; we did not record any slope of this magnitude but, in view of the evidence of our soundings about the nature of the bottom to the north and west of the island, such slopes may well exist.

## MARION AND PRINCE EDWARD ISLANDS

(Marion Island, 46° 49′ S, 37° 49′ E;
Prince Edward Island, 46° 36′ S, 37° 57′ E)

In April 1935, the 'Discovery II' visited Marion and Prince Edward Islands, and during a partial examination of the group continuous soundings were taken over a period of 10 hr., representing a distance over the bottom of approximately 65 miles. The track of the ship during this work is shown in Text-fig. 3*d*, p. 46.

The islands appear to lie on a submarine plateau and are steep-to, with considerable slopes from seawards at certain points; the maximum depth recorded over the distance of 12 miles between the two islands was 142 fm. (260 m.). South of the south-west corner of Marion Island the sounding was 896 fm. (1639 m.) at a distance of 3·5 miles from land, which is equivalent, approximately, to a slope of 14°. From this position, on a course almost parallel to the south coast of the island, soundings shoaled steadily to a depth of 174 fm. (318 m.) in a position 3 miles south of the south-east corner of the island. This coastal shelf appears to extend for at least 3 miles east of Marion Island, but its full extent was not determined.

East of Prince Edward Island the bottom is irregular and there are some very steep slopes. At one point, parallel to the coast at East Cape, the depth increased from 19 to 197 fm. (35 to 360 m.) in 0·5 miles, which is equivalent to an average slope of $19\frac{1}{2}°$; the major portion of this slope, however, was at an angle of 28°.

## BOUVET ISLAND

(54° 26′ S, 3° 24′ E)

During a series of cruises from Cape Town in 1938–9 further soundings were obtained at Bouvet Island on two occasions. Altogether, continuous soundings totalled $10\frac{3}{4}$ hr. and covered about 80 miles of the sea bed. As we had already suspected from the soundings taken here in October 1930 during a running survey and the search for Thompson Island (Herdman, 1932), the bottom was found to be very confused and irregular at depths less than 1300 fm. (2377 m.). There is a sharp rise (in one instance at an angle of approximately 20°) to a narrow submarine shelf of about 2 miles in width, from which the island itself rises fairly steeply. A section of the continuous sounding record taken in 1938, when approaching the island from the north, is shown in Pl. XXIX, fig. 1, and provides ample proof of the varied bottom in this neighbourhood.

## MAGELLAN STRAIT

Between November 1931 and November 1934, the 'Discovery II' made eight passages through Magellan Strait, but only on three occasions was the passage by way of the main channel throughout. The Cockburn Channel entrance to the western part of the main strait was used three times (October 1932, March and November 1934) and the entrance by Otway Bay and Sea Shell or Abra Channel once (December 1933). In October 1934 another route from the main strait to the Cockburn Channel was examined; this was by way of Pedro Sound, the Ackwalisnan Canal and Dynely Sound.

In December 1933 the 'Acadia' recorder unfortunately was out of action, but a full series of soundings was obtained at intervals of about 4 min. with the 'listening' sets, through Otway Bay and Sea Shell or Abra Channel. In March 1934 we were still without the recorder, but a good series of depths was determined over the whole length of the Cockburn Channel and into the main strait. In October of the same year the 'Acadia' recorder was again in use and we were able to obtain a continuous record over a period of $10\frac{1}{4}$ hr. during the passage from the main channel to sea via the Ackwalisnan Canal. On our return a month later the recorder was used for a total of 14 hr. and continuous soundings obtained from a position 55° 27′ S, 73° 40′ W to the main strait, via the Cockburn Channel.

All these channels are narrow and comparatively deep, with an extremely irregular bottom topography. At the northern end of Pedro Sound a maximum sounding of 232 fm. (424 m.) was obtained 4 cables off-shore, in a position where the width of the sound was only 1·15 miles. In the Cockburn Channel depths often exceeded 300 fm. (549 m.) and the maximum sounding of 377 fm. (691 m.) which was obtained here in October 1932 was in a position where the channel is barely 3 miles in width. The bottom here is extremely varied, and when the continuous record was taken, in November 1934, slopes of 10–15° were common; in one place the depth increased by 132 fm. (241 m.) in 3 min., which is equivalent, approximately, to a slope of 16°.

The entrance to the main strait by way of Otway Bay and Sea Shell or Abra Channel is very similar to those already described. The seaward entrance is shallow but once among the numerous islands through which the channel runs depths greater than 400 fm. (732 m.) were found over a considerable distance. The maximum sounding obtained by the 'Discovery II' in December 1933 was 478 fm. (784 m.), at a point where the channel is barely 2 miles in width. It is probable that the bottom here is also very varied but, as already stated, we were not able to obtain a continuous record on this passage.

## SOUNDINGS OFF ANTARCTICA IN THE MERIDIAN OF GREENWICH

Between July 1938 and March 1939 a series of cruises was made by the 'Discovery II' to the south and west of Cape Town (see Text-fig. 18, p. 89). By these cruises throughout winter and summer, over the same area, it was hoped to obtain valuable information on the seasonal changes across the Southern Ocean, between South Africa and the ice-edge. On each cruise the ship steamed to the latitude of 40° S, on or near the Greenwich meridian and then southward as far as possible. She then worked across the ice-edge to the meridian of 20° E and returned to Cape Town approximately on this meridian. Routine soundings were taken on all cruises, since the course was never quite the same for each cruise, and the recorder was used whenever possible. In the first five cruises the 'Discovery II' was stopped by pack-ice far from the Antarctic Continent; but in the sixth cruise (January 1939) she reached a point some 19 miles north of the 'barrier', and on the seventh (in early March) she reached the barrier and sighted land.

On the sixth cruise a continuous record was begun in 68° 55·2′ S, 02° 05·3′ E at a depth of 2121 fm. (3859 m.), and for a distance of 42 miles southward there was a slight but steady upward slope, not exceeding 2°, which reached a minimum depth of 846 fm. (1547 m.) in approximately 69° 35′ S, 02° 05′ E, 3 miles north of the ice-edge. In this last 3 miles the bottom became more irregular, with some increases in depth, but had begun to shoal again shortly before the ice was reached in 69° 37·9′ S, 02° 07·8′ E. Here the depth was 1052 fm. (1924 m.), and from the soundings obtained 18 miles south of this position on the next cruise it would appear that this steady rise continues for some miles and that there is finally a much steeper slope up to the continent.

On the last of the repeated cruises (in March 1939) the barrier was first sighted in 69° 15′ S, 00° 12·1′ E and the sounding close alongside the northernmost ice-cape was 1114 fm. (2037 m.). Continuous soundings had been commenced some miles north of this point, in a depth of 1518 fm. (2776 m.), and records were obtained along the barrier to a position in 69° 05′ S, 04° 30′ E, a distance of 140 miles. The recorder was run for 28 hr. during two days and the track of the ship is shown in Text-fig. 16 (p. 86).

The depth shoaled fairly rapidly towards the barrier in this longitude, the slope of the bottom from seaward averaging $9\frac{1}{2}°$, and this slope continued towards the land. In 69° 58·2′ S, 01° 31·0′ E the ship was probably about 5 miles from land and the sounding was 105 fm. (192 m.). As will be seen from the track in Text-fig. 16 the course then lay to the north-east and the depth increased rapidly. When the

'Discovery II' turned east, in approximately the longitude of 01° 45′ E the sounding was 648 fm. (1185 m.) and when she stood away from the ice during the hours of darkness the depth was 795 fm. (1450 m.) in 69° 47·8′ S, 02° 21·1′ E. Soundings remained variable on the return to the barrier on the following day, although there was a sharp rise in the bottom at one place of 328 fm. (600 m.) in approximately 3·5 miles. This rise occurred between the depths of 815 and 487 fm. (1491 and 891 m.).

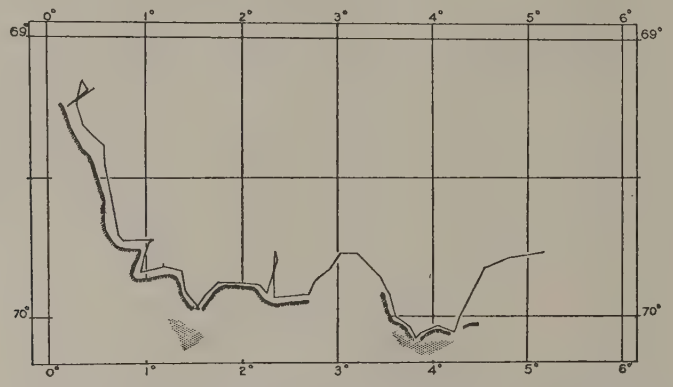


Fig. 16. Track of ship along ice barrier and coast of Antarctica, between the longitudes of 0° 10′ E and 4° 30′ E. Continuous recording of soundings throughout.

Shortly after the return to the barrier the ship was forced to the north by a field of bergs surrounded by heavy pack-ice, and soundings reached a maximum of 1010 fm. (1847 m.) in 69° 54·8′ S, 03° 32·1′ E. From this position the soundings again shoaled rapidly towards the land and after a steady slope a depth of 60 fm. (110 m.) was obtained 3 cables off-shore, in 70° 04·6′ S, 03° 49·2′ E. Land was again approached a few miles farther east and the least sounding obtained was 117 fm. (214 m.). Course was then altered to avoid pack-ice and to stand off the coast during the dark hours, but the weather deteriorated rapidly during the night and it was not possible to resume the survey.

## THE CONTINENTAL SHELF OF ANTARCTICA

This short survey of 140 miles of the ice barrier revealed the interesting fact that over this distance there was virtually no continental shelf in the sense generally understood. Unfortunately, the pack-ice which surrounds the Antarctic Continent throughout the greater part of the year in most sectors makes the approach difficult, and it is only during late summer or autumn that ships can expect to close the land. It is not possible, without much more information than we now possess, to forecast, even remotely, the incidence of pack-ice, and thus any approach to the continent will remain for some years largely a matter of chance. Aerial reconnaissance, however, would be of considerable assistance in a clear ice year.

The information which has already been obtained from various approaches to the Antarctic Continent, and from running surveys of some short sections of the coast, leads us to believe that in some places the continental shelf is almost completely absent; one such area has just been described. Similar conditions are to be found in other parts of the Atlantic sector, and over considerable lengths of the coast between the meridians of 5° E and 60° E. There appears to be a wide shelf to seaward of the coasts of the Weddell Sea, and off the South Shetlands and South Graham Land there is a marked shelf, some 60–70 miles in width, which becomes wider as it continues south-west into the Bellingshausen Sea. No ship has ever reached the land between here and the eastern side of the Ross Sea,

but soundings obtained on the Pacific ice-edge suggest that a wide continental shelf exists in this sector. No land has been seen to the south from the various ships which took these soundings, and it may therefore be assumed that the shelf has a minimum width of 15 to 20 miles.

Off Marie Byrd Land and as far west as Cape Colbeck the bottom rises abruptly to a narrow shelf which widens out into the shelf which extends over the whole area of the Ross Sea (see Pl. XXV). At Cape Adare, at the north-western corner of the Ross Sea, the bottom again rises sharply from deep water to a narrow coastal shelf, and these conditions prevail to the west as far as the meridian of 158° E. Between this meridian and that of 130° E there is a wide area to seaward of the land where shallow soundings obtain, and in January 1938 off Adélie Land the 'Discovery II' took continuous soundings with the 'Acadia' recorder between 63° 53·1′ S, 135° 16·8′ E and 66° 13·8′ S, 139° 46·4′ E. The distance run was 170 miles, in approximately 19 hr., and the true course was south-east. Unfortunately, the weather during the last 12 hr. of this run was overcast and there were intermittent heavy snow squalls; these conditions, together with the unreliability of the magnetic compasses due to the close proximity of the South Magnetic Pole, made it impossible to assign positions for the soundings which would be acceptable for plotting on the charts. However, the accuracy of the positions, which were obtained by dead reckoning, is sufficient to prove the existence here of a wide continental shelf.

The run in to the land commenced at depths of approximately 2200 fm. (4023 m.) and the bottom remained fairly level at this average depth for about 40 miles. In approximately 64° S, 135° 30′ E the character of the bottom began to change and depths became very irregular. Soundings in general shoaled gradually to depths between 1200 and 1300 fm. (2195 and 2377 m.) during the next 60 miles of the run, and then remained approximately at this level for some 15 miles farther to the south-east. The bottom was still very irregular and there was no indication of a slope up towards land when, unfortunately, the magnetic coil in the head of the transmitter fused. A new coil was fitted and continuous soundings were resumed within an hour, but by this time the depth was 712 fm. (1302 m.) and it was obvious from the record that the slope up to the continental shelf had commenced. The edge of the shelf was reached in a distance of 3·65 miles from the resumption of soundings, at a depth of 247 fm. (452 m.). This represents a slope of just over 7° on a line of approach which was probably at an angle of 45° to the lines of the contours; the actual slope, measured at 90° to the contours, will almost certainly be greater.

After passing over the edge of the shelf which, at this point, lay in 65° 17·3′ S, 138° 19·5′ E (50 miles, approximately, north of Adélie Land), depths gradually increased to a maximum sounding of 335 fm. (613 m.) in 65° 39′ S, 139° 08′ E. From this position soundings shoaled fairly rapidly to a depth of 244 fm. (446 m.) in 65° 45′ S, 139° 22′ E and continued near this level until the deterioration of the weather forced us to abandon the approach in approximately 66° 14′ S, 139° 46′ E. The sounding in this position was 265 fm. (485 m.).

West of Adélie Land, as far as the meridian of 100° E, the line of the coast is in considerable doubt, but there is some slight indication of a fairly wide submarine shelf to seaward of the land. Between 100° E and 60° E the presence of a continental shelf is in general well established; its width is variable but gradually narrows towards the west. In 98° E it stretches out for at least 130 miles from the continent, but off Kemp Land, in approximately 60° E, the seaward limit of the shelf lies not more than 30 miles off the land.

Profiles, based on the continuous sounding records, have been drawn for the approach to the continent in the meridian of Greenwich and also for the run in to Adélie Land; they are shown in Text-fig. 17 (p. 88) and, in conformity with the profiles across the Scotia Sea and Arc, the vertical scale is magnified 25 times.

We do not propose, in this report, to discuss in detail this question of the continental shelf surrounding Antarctica. The presence of a well-defined shelf only in certain places may be found to be related closely to the existence, among others, of features such as the Kerguelen-Gaussberg Ridge

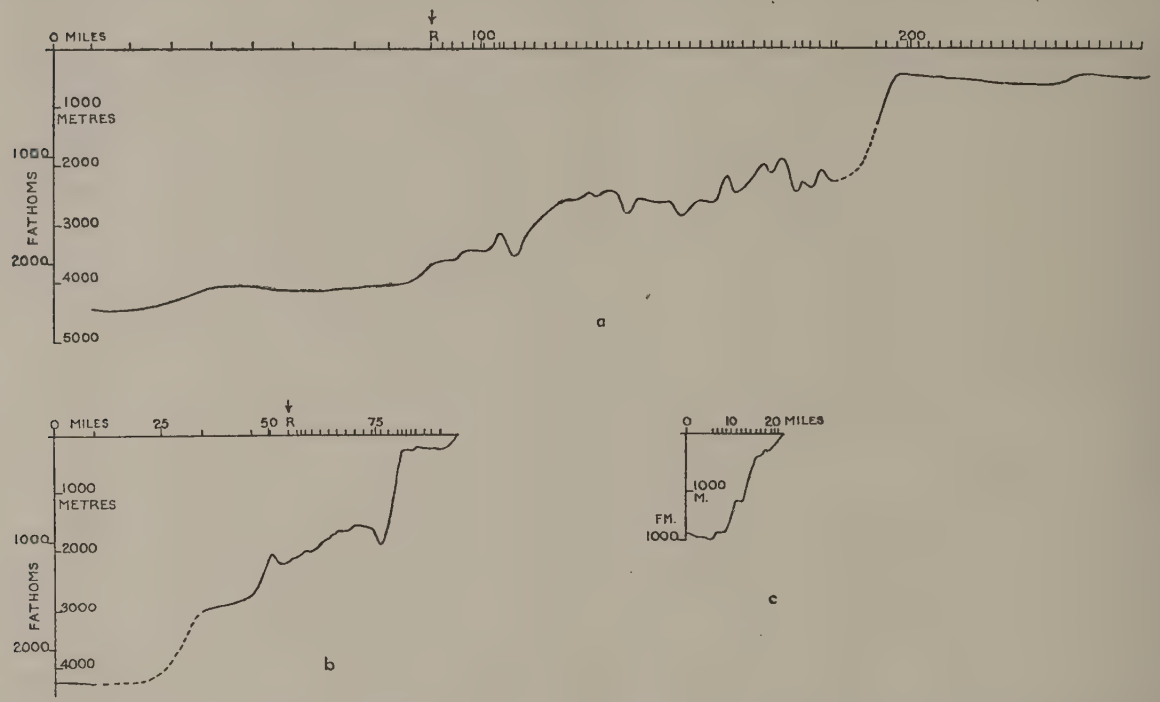


Fig. 17. Approaches to Antarctica. Vertical scale, ×25. Positions of soundings are marked on the horizontal scales. (*a*) Towards Adélie Land, on a south-easterly course. Continuous record from point marked *R*. Note wide continental shelf in this area. (*b*) In the meridian of Greenwich. Continuous record for 35 miles. Very narrow continental shelf. (*c*) In the longitude of 3° E. Bottom rises abruptly to the land from a depth of 1000 m. (547 fm.).

and the Scotia Arc. On the other hand, the width of the shelf may depend on the geological structure of the continent and the incidence of large glaciers. In order to arrive at any conclusion, however, about the relationship of the shelf with the various ridges which approach Antarctica from seaward, it will be necessary to examine the many thousands of oceanic soundings taken by the Discovery Investigations around the continent; it will, perhaps, be more suitable to revert to the continental shelf of Antarctica when we consider these soundings. It is hoped to begin this work in the near future.

## SOUNDINGS IN OTHER LOCALITIES

The majority of soundings taken during the work of the Discovery Committee (and all of these outside the Atlantic sector) are from the 'Discovery II'. The principal tracks of this ship between 1932 and 1939 are shown in Text-fig. 18 (p. 89), and since soundings were taken at intervals of 8 or 9 miles throughout nearly all of these routes, it will easily be understood that they provide a very large number of new oceanic soundings south of 40° S. These soundings, added to the existing data, might justify the construction of a new bathymetric chart of the Southern Ocean. It is hoped to prepare such a chart later on, but in view of recently published charts and the prospects of additional data, it is thought better not to include it with the present report.

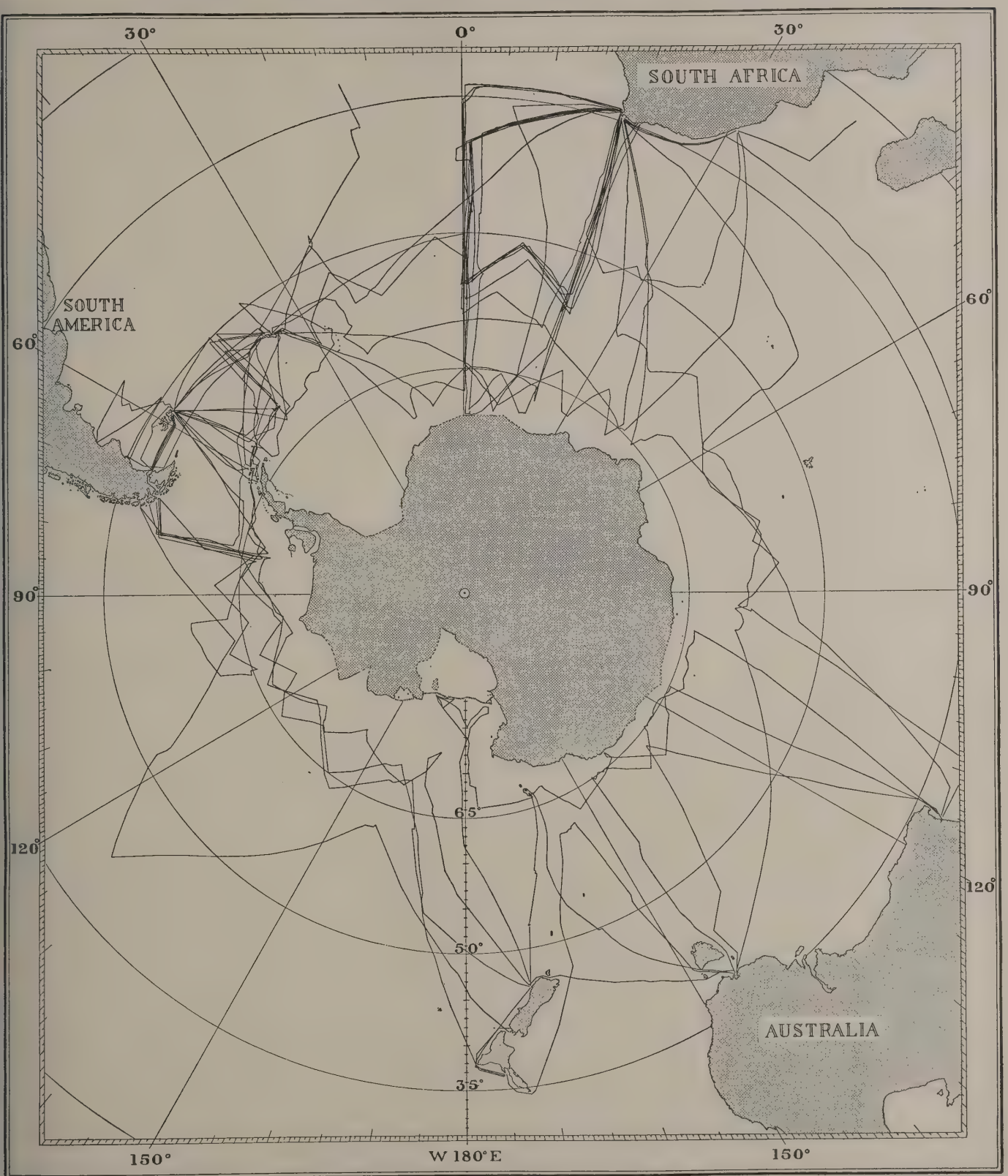


Fig. 18. Oceanic tracks of R.R.S. 'Discovery II' between May 1932 and March 1939. With the exception of a few unimportant gaps these tracks may be taken to represent lines of soundings.

Certain features in our general oceanic sounding work, however, deserve attention in this report, and among these are the recently discovered bank in the latitude of 42° S, close to the Greenwich meridian, and a series of soundings in the Ross Sea. We should also mention the soundings on the Kerguelen-Gaussberg Ridge.

## DISCOVERY BANK

(Text-fig. 19)

The Discovery Bank was first located by the 'Discovery II' in May 1936. It was then crossed from north to south after a sounding of 560 fm. (1024 m.) had been reported in a position 41° 50′ S, 00° 01·7′ E. This comparatively shallow sounding followed a depth of 2287 fm. (4182 m.) obtained about 17 miles to the north. Soundings were then taken more frequently and a bank of less than 1000 m. (547 fm.) in depth was traced to the south for some 30 miles, the minimum depth obtained being 367 fm. (671 m.) in 42° 05′ S, 00° 06·2′ E. Later in the same year a good line of soundings was obtained with the recorder 14 miles east of the previous line. In the following year only one sounding, of 628 fm. (1148 m.), was obtained on the Bank.

The repeated cruises made by the 'Discovery II' to the south and west of Cape Town in 1938 and 1939 (see p. 85) presented further opportunities to obtain soundings on this bank. On the seven cruises which comprised this series the bank was crossed from north to south on five occasions and an attempt was made to run a line of soundings from west to east, to obtain evidence of the probable existence of two peaks, separated by moderately deep water. Unfortunately, bad weather prevented the completion of this line, but reference to Text-fig. 19 will show that a north to south line run subsequently leaves little doubt that two such peaks do exist. On the seventh cruise a line of soundings was attempted from north to south, in the longitude of 02° 30′ E, and, although soundings could not be obtained under way, conditions were such that any depths of less than 1000 fm. (1828 m.) should have been recorded.

The Discovery Bank lies in a stormy latitude and conditions are usually a severe hindrance to echo sounding. In consequence there are some unavoidable gaps in our lines of soundings but despite the adverse conditions agreement between the various lines was generally good.

Within a few weeks of our final run across the bank, the German ship 'Schwabenland', on her passage north from the ice barrier, obtained a series of soundings on the Discovery Bank, almost on the meridian of Greenwich. Through the courtesy of the Hydrographer of the Navy we have now obtained a list of these soundings, but unfortunately the positions given for the soundings in the critical area are noted by the ship as not being entirely reliable, on account of bad weather. When plotted, these soundings are not in agreement with our line of May 1936, which lies in approximately the same longitude, but from a close examination of all the available data it is probable that, on account of bad weather, our positions at this time are also not fully reliable, and that south of latitude 41° 30′ S our line should be plotted from 2 to 4 miles to the west of the position now shown. It seems likely that the positions given for the 'Schwabenland' soundings, between the latitudes of 43° S and 41° 30′ S, are some 3 to 4 miles north of their true position. Displacement to the west of our soundings and to the south for the German observations would bring these results into line with the remainder of our work on the bank but, with the exception of increasing slightly the north to south dimension of the area less than 500 m. (273 fm.) in depth, to conform to that determined by the 'Schwabenland', there would be little to be gained by moving our line, especially as we lack the necessary data from the ship's log-book to check further on the 'Schwabenland's' positions.

In Text-fig. 19, which has therefore been compiled from our soundings only, the actual depths are not given but the positions of the soundings are shown as dots. In most instances the contours, which

are in metres, have been determined directly from the 'Acadia' recorder, but it should be understood that, when continuous soundings are thus being taken, many more depths than those shown could have been plotted. For convenience in reading off the soundings from the record and determining the positions, soundings have been plotted at intervals of five minutes of time, over such distance as the record has been legible. It should, however, be remembered that with varying weather the speed of the ship was not necessarily the same for each crossing and, consequently, that the distance between soundings on different lines, being based on a fixed time interval, varies considerably.

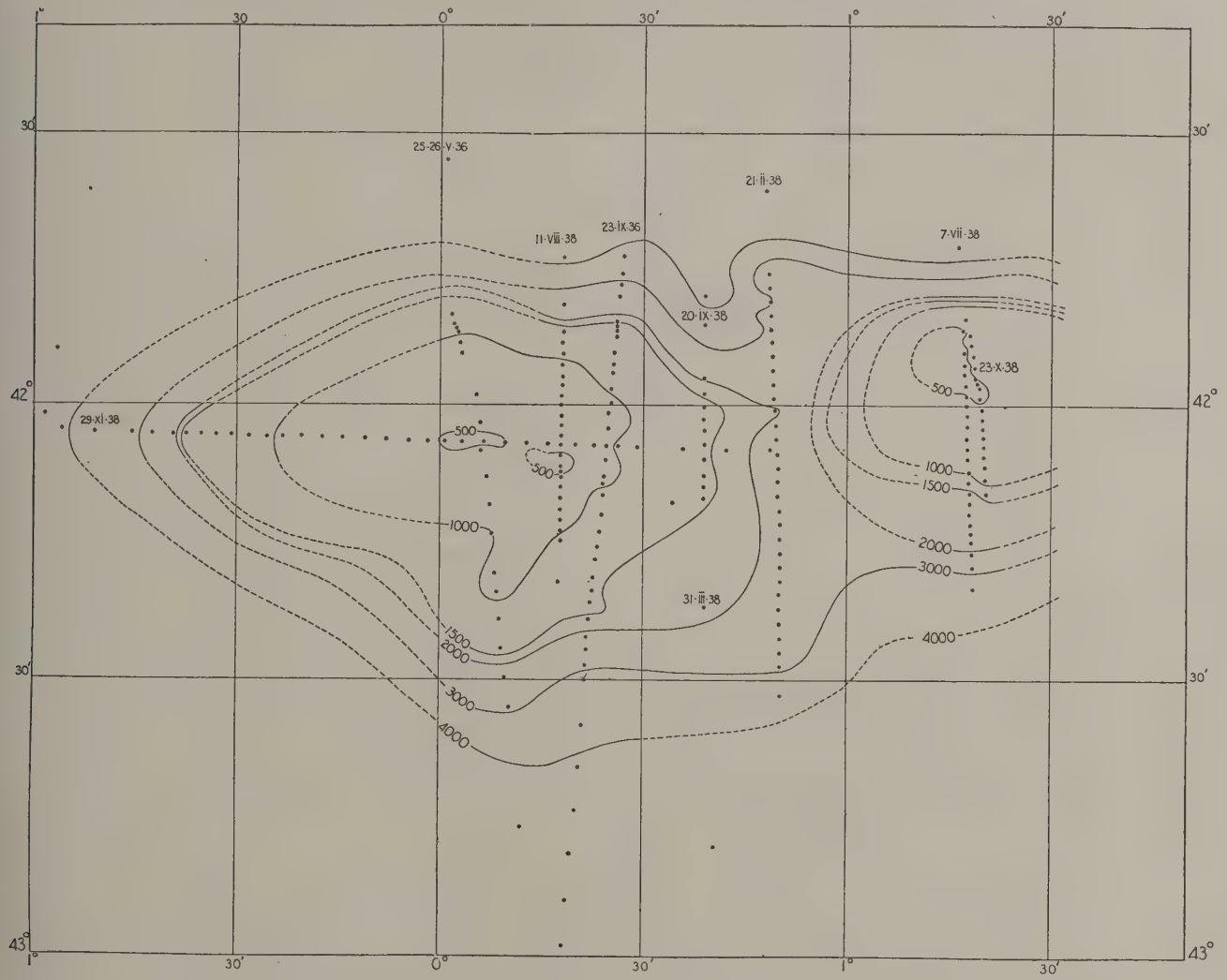


Fig. 19. Discovery Bank, contours in metres. Positions of soundings shown as dots.

The rise of the bottom on the northern side of the Discovery Bank is fairly steep, the average slope being approximately 10°. The maximum slope so far determined is approximately 12°. On the southern side the fall away to deep water is much less marked, the slope from the 1000 m. to beyond the 4000 m. contour averaging approximately $3\frac{1}{2}$°. The maximum slope barely exceeds 4°. The extent of the shallow water on the western half of the bank appears to have been determined with reasonable accuracy and depths of less than 1000 m. (547 fm.) cover an area of about 700 sq. miles. Two small areas with depths of less than 500 m. (273 fm.) and a minimum so far determined of 457 m. (250 fm.) have been

found on this side, and further soundings here may well show that these are part of a continuous ridge across the top of this part of the bank, although, as noted above, the 'Schwabenland's' observations suggest that this area of less than 500 m. (273 fm.) in depth may be more of a plateau than a ridge. We have not obtained sufficient information to determine the extent of the shallow water on the eastern half of the bank, though it seems probable that it extends some miles farther to the east. The least depth found here was 390 m. (213 fm.).

Two attempts were made to dredge on the Discovery Bank and the second, in November 1938, was successful. This was at St. 2493, in 42° 03·9′ S, 00° 03·5′ E, where three large rocks, a large number of smaller rock fragments and a mass of pebbles were obtained from a depth of 472 m. (258 fm.). Many of these pebbles were round and waterworn. All living organisms were smashed by the weight of rocks and pebbles but it was evident that a large species of sea-urchin and two or three species of Crinoid were common.

## THE ROSS SEA

(Pl. XXV)

Soundings taken by Rear-Admiral Byrd's ship the 'Bear of Oakland' between the years 1933 and 1935 and by the 'Discovery II' in 1936 have provided much valuable information on the topography of the bottom of the Ross Sea. Prior to the work of these two ships our knowledge of the outlines of the sea bed here was scanty, and the few bathymetric charts available were based on a small number of scattered soundings, most of which were near the land on the western side, or were adjacent to the Ross Ice Barrier.

The most recent bathymetric chart of the Ross Sea, on a scale comparable to that of our present chart, is that of the American Geographical Society (1928). This map, of which sheets 3 and 4 cover the Ross Sea, includes a depth contour at 500 m. (273 fm.). Maps of a more recent date which include this area have been published, but they are on a much smaller scale, and the lack of a 500 m. contour in the Australian map of Antarctica (see p. 67) for instance, prevents the inclusion of most of the interesting features of the bottom topography of the Ross Sea. The U.S. Chart of Antarctica (see p. 67) also shows no depth contour above 500 fm. (914 m.), but more use appears to have been made of soundings taken by the 'Bear of Oakland'.[1]

Most of the soundings taken by the 'Bear of Oakland' were obtained during direct passages to and from the Bay of Whales and while cruising to the north and east of Cape Colbeck. The list of soundings also includes observations made during a cruise to meet the 'Discovery II' (in approximately 72° S, 171° W). Further soundings available from the same source were taken on the return of the 'Bear of Oakland' from New Zealand in 1935, when a cruise was made towards McMurdo Sound and thence south to Ross Island. From here the line of soundings ran across to the Bay of Whales, following closely the face of the Ross Barrier.

The soundings obtained by the 'Discovery II' in 1936 are shown in black in Pl. XXV and their location was determined largely by the necessity for quick passages, to and from the Bay of Whales, through the belt of pack-ice to the north of the Ross Sea. Some scientific work, however, was possible near the Bay of Whales and in the neighbourhood of Ross Island, and the soundings thus obtained have been of material aid in linking up our work with that of the 'Bear of Oakland'.

Our soundings are mostly in excellent agreement with those of the 'Bear of Oakland' where the two ships covered the same ground; but they also provide new information which, when added to the

[1] It is possible that the compilers of the Australian map did not have access to the full list of echo soundings taken by the 'Bear of Oakland'. These were published in manuscript form only, by the Woods Hole Oceanographic Institution, in October 1935. Reference in literature to this list does not appear to have been made other than by Roos (1937).

previous data, calls for some modifications of Roos's interpretation (1937) of the 'Bear of Oakland's' soundings. Roos refers to the 'Pennell Bank' as extending right across the Ross Sea from north-west to south-east; he also refers to the 'Iselin Bank', an isolated feature in approximately 72° S, 177° W. The conception of a shallow bank stretching across the Ross Sea from north-west to south-east appears to have originated with the American Geographical Society's bathymetric map of 1928, and the name 'Pennell Bank' for this feature was proposed by Griffith Taylor (1931). From the evidence now available it does not appear that this bank is continuous at depths less than 500 m. (273 fm.) across the whole width of the Ross Sea. There is probably a wide area in the north-western part of the Ross Sea where depths of less than 500 m. will be found, and it is highly probable that this is separated by a distance of about 60 miles from two moderately long but narrow areas of less than 500 m. in depth in the south-eastern part of the sea. Both ships obtained a few soundings of slightly less than 500 m. (273 fm.) in this gap, but reference to our present bathymetric chart (Pl. XXV) will show that there can be little doubt of the break in the continuity of the 500 m. contour. At the same time there can be no doubt that the general level of the bottom in the gap is above that of the south-western part of the Ross Sea.

At the eastern side of the larger bank to the north-west of the Ross Sea there is a narrow ridge, some 60 miles in length, where the soundings do not exceed 250 m. (137 fm.). Both the 'Discovery II' and the 'Bear of Oakland' ran along this ridge, the latter ship obtaining a minimum depth of 106 m. (58 fm.) in 74° 27′ 45″ S, 179° 58′ W. Since the existence of the original continuous bank across the Ross Sea now is doubtful, we propose that the name 'Pennell Bank' can be appropriately used for this limited area of less than 250 m. (137 fm.) in depth.

In our interpretation of the bottom relief in the region of the so-called 'Iselin Bank' we are of the opinion that this feature is not an isolated bank as suggested by Roos. It seems more probable that it is part of a considerable extension to the north, and finally to the north-east, of the wide shallow area in this part of the Ross Sea.

The main axis of this large and comparatively shallow region now appears to lie more in a south-west and north-east direction. To the west, between the bank and the Victoria Land Coast, there is a gully with an average depth of between 600 and 700 m. (328–383 fm.) and to the south-west depths of over 750 m. (410 fm.) are found north of Ross Island; these depths continue east for some miles along the face of the Barrier and it may well be that greater depths exist under the ice shelf itself.

It is, perhaps, on the eastern side of the Ross Sea that the greatest value attaches to the soundings of the 'Bear of Oakland'. Before the work done by this ship the information available in this area consisted of six soundings north of the latitude of 73° S and a few isolated depths of less than 300 fm. (549 m.) off-shore between Discovery Inlet and Biscoe Bay. Consequently, our knowledge of the topography of the bottom here was largely guesswork, but two excellent lines of soundings direct to the Bay of Whales, and the run up north to meet the 'Discovery II' in 72° S, have now provided sufficient evidence on which to draw a series of depth contours.

It is now evident that, at its seaward limit, the Ross Sea shelf runs approximately in a north and south direction between the latitudes of 72° S and 76° S. Over this distance the shelf is wide and the slope from seaward is only moderately steep. Southward from the latitude of 76° S the trend of the contours is almost in an east and west direction and the width of the shelf is reduced considerably; there is also a marked increase in the angle of slope between the 2000 m. and 500 m. contours. Further work by the 'Bear of Oakland' to the north-east of Cape Colbeck shows, as already noted by Roos, that the shelf is reduced in width to barely 15 miles, with an even sharper slope from seaward.

There still remains much work to be done in the Ross Sea before a more accurate conception of the bottom relief can be provided. Many more soundings are required between the latitudes of 73° and

76° S, west of the meridian of 179° E, and there is a serious gap to the east of the Pennell Bank. Here, between the 500 m. (273 fm.) and 3000 m. (1641 fm.) depth contours there is only one sounding in the distance of about 100 miles which separates the lines of soundings taken by the 'Discovery II' and the 'Bear of Oakland'. North of the Ross Barrier there is a large area, triangular in shape, where there are no soundings between the series obtained by the 'Discovery II' in 1936.

Few soundings have been obtained off the coasts of Victoria Land. Such as have been taken, however, suggest that this is a region of considerable interest, for in many places where the land slopes steeply down to the sea the bottom appears to descend rapidly to the 500 m. (273 fm.) contour or below. There is little or no shallow water for any distance from the coast, and just south of Terra Nova Bay (in approximately 73° S) a depth of 350 fm. (640 m.) is shown on British Admiralty Chart No. 3206 approximately $2\frac{1}{2}$ miles from the land. From the same source another sounding, near Cape Roberts (in approximately 77° S), shows a depth of 313 fm. (572 m.) only 3 miles off-shore. Off the Drygalski Ice-tongue existing soundings indicate the existence of a narrow trench, with a depth of slightly over 1000 m. (547 fm.).

Despite these gaps it is probable that the main features of the bottom relief of the Ross Sea are now tolerably well known; yet the results of our hydrological and biological observations made in the southern part of the sea are difficult to reconcile with our present interpretation of the bottom topography.

Deacon (1937, p. 115) in his remarks on the hydrological observations in this area supports the conception of a relatively shallow ridge, at depths less than 500 m. (273 fm.), between Cape Adare and King Edward VII Land, but he also suggests that there can be no channel through this ridge near the coast of Victoria Land. We have already shown that a continuous ridge at this depth across the Ross Sea almost certainly does not exist, but soundings in the gap indicate that the depth here is generally 100 to 150 m. (55–82 fm.) less than that of the area immediately to the south-west. This rise from the moderate depths of the southern part of the Ross Sea is probably sufficient to prevent the escape to sea of the cold bottom water, but on the present evidence from soundings it is difficult to agree with Deacon's suggestion that there is no deeper channel along the coast of Victoria Land. There can be little doubt now that such a channel can be traced as far north as the latitude of 73° S, and although there are only a few soundings north of this point it seems improbable that there can be any shallow connexion between Victoria Land and the 500 m. bank between here and Cape Adare.

## KERGUELEN-GAUSSBERG RIDGE

The Kerguelen-Gaussberg ridge extends over a wide area, in a south-easterly direction from the island of Kerguelen to the Antarctic Continent. Rising on the average some 2500 m. (1367 fm.) above the general level of the ocean bottom on either side, the ridge separates the Atlantic-Antarctic and Australian-Antarctic basins. It exerts a profound influence on the hydrology of these regions of the Southern Ocean.

Between Kerguelen and Heard Island the ridge is comparatively steep-to on the western side and slopes away to deep water more gently in the east. South of latitude 55° S these conditions are reversed and it is on the eastern side of the ridge that the slopes become abrupt. From this latitude to that of 60° S the topography of the bottom is varied and there are two well-marked shallower areas. One of these is Banzare Rise, on the western side of the main ridge, which was discovered by the B.A.N.Z. Antarctic Research Expedition in 1929. The minimum depth determined by them, during two crossings of the rise, was 351 fm. (642 m.), in 58° 50′ S, 77° 44′ E. The U.S. Chart of Antarctica (No. 2562) and the Australian map of Antarctica both show a sounding of 103 fm. (188 m.) on the Banzare Rise; the source of this information, however, is not known to us.

On the extreme eastern side of the main ridge, south of latitude 55° S there appears to be a fairly well-defined narrow crest at depths less than 1000 fm. (1829 m.), and from the information now available it seems likely that this crest extends from a position a few miles south of Heard Island to the latitude of 58° S, following the line of the eastern side of the main ridge. At the extreme south-eastern end of the Kerguelen-Gaussberg ridge there is another well-marked shallow area, the Gribb bank (discovered by the whale-catcher 'Gribb' in 1937), which appears to rise sharply in approximately 62° S, 88° E; but owing to lack of soundings on the eastern side of the ridge, between this bank and the crest mentioned above, we cannot state whether Gribb bank is an isolated feature or whether it is part of a possible continuation of the crest south of latitude 58° S. It seems probable, however, that Gribb bank will be found to be connected with the crest and that it forms part of a shallower portion of the main ridge extending from Kerguelen to the latitude of 62° S.

The 'Discovery II' crossed the Kerguelen-Gaussberg ridge while skirting the pack-ice from west to east in April 1932, November 1935 and December 1937. Unfortunately the northern limit of the ice differed only slightly on each occasion and all three crossings were consequently made within a few miles of each other. In 1932 soundings were being obtained with the 'listening' type deep-water set, at intervals of distance varying with the weather, but which were between 2·5 and 4·5 miles; the minimum sounding was 956 fm. (1784 m.), in 56° 39·5′ S, 78° 37′ E. In 1935 continuous soundings over a distance of 75 miles were obtained with the 'Acadia' recorder, between 57° 27·5′ S, 74° 38·6′ E and 56° 55·2′ S, 76° 46·7′ E, and the minimum depth recorded was 1217 fm. (2226 m.) in 57° 04·7′ S, 76° 08·7′ E. Routine soundings at intervals of approximately 4 miles were then resumed, at a depth of 1397 fm. (2555 m.), but the depth again shoaled and a sounding of 1044 fm. (1909 m.) was obtained in 56° 32·8′ S, 78° 24·1′ E. The deep water of the Australian-Antarctic basin was reached in 56° 59·5′ S, 81° 23·6′ E, at a depth of 2548 fm. (4660 m.).

Continuous soundings for a distance of 275 miles were possible during the crossing of the Kerguelen-Gaussberg ridge in 1937 and a zigzag course was followed between 57° 26·6′ S, 74° 06·6′ E and 56° 56·5′ S, 80° 28·7′ E (see Text-fig. 2*c*). Depths generally were less than 3000 m. (1641 fm.) over the whole distance, and were under 2000 m. (1094 fm.) between 56° 53·2′ S, 78° 01·2′ E and 57° 18′ S, 80° 13·2′ E. The minimum sounding recorded was 910 fm. (1664 m.) in 57° 31′ S, 79° 38·8′ E. It will be of interest, perhaps, to mention here that at the point where the 1937 line crossed the 1932 line of soundings (in 56° 50′ S, 77° 54·5′ E) the sounding recorded in 1937 was 1164 fm. (2129 m.), which is only 15 fm. (28 m.) less than the sounding of 1179 fm. (2154 m.) obtained 1·2 miles north-east of this position in 1932. With the varied condition of the bottom prevailing here such agreement is gratifying.

The recorder charts for 1935 and 1937, especially the latter, showed by the multiple echoes recorded at many points that the bottom on the Kerguelen-Gaussberg ridge was extremely irregular at depths greater than 1100 fm. (2012 m.). At depths less than this conditions were the exact opposite; there was a completely regular bottom and no signs of any multiple echoes.

## APPENDIX I

### DEEP-WATER ECHO-SOUNDING SET

In 1933 an 'Acadia' type recorder was fitted to the deep-water echo-sounding set in the 'Discovery II'. This recorder, the scale of which was graduated in fathoms from 0–250, had an unlimited range, with phasing by 100 fathom steps: i.e. it was possible to 'step-back' or 'step-on' the transmissions so that the echo would always appear on the record. The principle of this recorder was quite simple: a transmission was sent out by the hammer normally at every complete revolution of the phasing switch,

i.e. every $2\frac{1}{2}$ sec. The returning echo was detected by a carbon-granule hydrophone, amplified, rectified and recorded on sensitized paper traversed by a stylus pen driven by the transmitter switch. The paper, which was supplied dry, had been sensitized during manufacture with a solution of starch and potassium iodide and, in the 'Acadia' pattern recorder, was wetted for use by passage over a wick which was fed from a tank behind the paper. When the stylus was traversing the paper and an echo or signal was received, the current at that moment passing through the stylus electrolysed the starch-potassium iodide solution in the wet paper and the iodine thus set free made a stain which commenced at the precise moment when the echo was received. As the paper travelled only at approximately 11 in. per hour past the stylus, the spacing of the returning echoes was so close that an almost continuous echo line was produced. In bad weather it was sometimes difficult to distinguish the echo mark from the other marks caused by extraneous noises in the hydrophone, especially in depths of more than 500 fm. (914 m.). Passage of the ship through brash ice, or pack-ice, had a similar effect (see Pl. XXX, fig. 1). It was possible to adjust the strength of the echo current by increasing or decreasing the sensitivity of the amplifier, but this had the disadvantage of having a similar effect on the strength of the water noises set up in the hydrophone. Therefore, in rough weather, it was often necessary to plug in the headphones to the telephone circuit and listen for the returning echo, marking it on the record, if necessary, with the electric pencil provided. Difficulty was also met when the returning echo coincided with an outgoing transmission, since the band, or mark, set up on the record by the transmission was of such intensity that an echo might be blanked out for a distance representing some 20 or 30 fm. on the record. A switch, however, was provided whereby it was possible to cut out any required number of transmissions without interference to the receiving circuit, and by careful manipulation of this switch it was possible to trace the line of the echoes through the transmission band. A typical example may be seen in Pl. XXXI, fig. 1. Without the use of the switch this transmission band would have completely obscured the echo at a depth of 1000 fm. (1829 m.). This cut-out switch was also used in determining the correct phase for soundings in waters of unknown depth. It will be appreciated that since the phase switch or dial was graduated only from 0 to 1000 fm., and that since a transmission was made automatically each time the phase switch arm passed zero, then an echo which appeared on the paper at a scale reading of, say, 200 fm., might equally represent 200, 1200, 2200, etc. fm. The correct phase, however, could easily be determined by cutting out all transmissions after the first, listening on the telephone circuit, and watching the number of times the phase switch arm had rotated before the echo was heard.

The recorder mechanism was driven by a governed electric motor, the speed of which required checking and adjustment as the set warmed up. A careful check with an accurate stopwatch was made therefore during long runs and the rate noted at intervals for the subsequent correction of the soundings. A note also was required, on the actual record, of any correction to the timing. If, for example, the motor ran fast by, say, 1% for 600 min. (which was quite a common period during survey work) the minute markings automatically recorded on the paper would at the end of the run be 6 min. ahead of the correct time and all the soundings recorded would be 1% too deep. This error in depth was negligible in soundings less than 100 fm. (183 m.) but, as we were usually approaching an unknown or imperfectly surveyed anchorage at the end of such a run, it was imperative for the subsequent plotting of the soundings that the correct time should be known for each depth plotted. Eventually it was found that nearly correct running ensued if the case containing the mechanism was left open; such minor corrections of speed as were then necessary could be applied by means of a sliding resistance which we fitted in addition in the ordinary governor circuit.

Throughout the whole period in which the recorder was in use, few repairs were needed apart from small mechanical and electrical adjustments. On one occasion there was a complete breakdown in

the amplifier due to a defective rectifier. Since spares were not readily available it was necessary to return the amplifier to the makers for repairs, and for some months only the 'listening' gear could be used. The only other serious trouble met with was the failure of the H.T. dry batteries to maintain a correct voltage. During survey work it was necessary to keep open the door to the echo cabinet and chart room, and the deterioration of the batteries is attributable to unavoidable exposure to much cold and damp weather. Some deterioration, however, also took place in new batteries stored on board. Eventually it was found best to replace the dry batteries with accumulators, and these were charged up every night during periods of surveying.

The old 'listening' type receiving gear needed little attention, but the transmitter (or hammer) gave considerable trouble, and eventually broke down in December 1934, during a survey of the South Shetland Islands. Temporary repairs were carried out by the ship's engineering staff, but the hammer was found to be worn out, and a new one was installed on the existing base plate some months later. This unit worked on the whole satisfactorily until 1939, and no replacements were required other than a new balanced head in 1938. The deep-sea hydrophone gave a certain amount of trouble in 1935 but a new unit was fitted at sea, through the sluice-valve provided, and from then until 1939 no further serious trouble was experienced. When the old unit was removed in 1935 it was found that the probable cause of the trouble was damage to the face by careless chipping of the adjacent hull plating in dry-dock. Precautions were then taken at other occasions of dry-docking to prevent a recurrence of such damage.

## SHALLOW-WATER ECHO-SOUNDING SET

As stated on p. 43 a magnetostriction echo-sounding set, with a Mark XIID recorder, was fitted in the 'Discovery II'. The tanks containing the oscillators forming the transmitter and receiver were fitted to port and starboard of the centre line of the ship in No. 2 double-bottom freshwater tank. This position was 55 ft. from the fore perpendicular, and about 6 ft. forward of the position originally used for the Admiralty Pattern 751 sonic type receiver. The bridge instruments were fitted in the echo cabinet on the port side of the chart-house; the recorder, amplifier and contactor unit occupying no more space than that originally provided for the sonic receiving gear. H.T. and L.T. supply were arranged from the accumulators already in use for the deep-water set. No trouble was ever experienced with the transmitter or receiver, and when the author of this report had occasion to visit the ship during the course of his war-time duties with the Admiralty it was found that after $5\frac{1}{2}$ years immersion in a double-bottom water tank the transmitter and receiver were still functioning correctly. The recorder gave little mechanical or electrical trouble except for some difficulty with the change-speed gear box. Finally, to avoid their frequent renewal the train of gears for the high speed was removed and the machine solely used for sounding in fathoms. A serious defect, however, was the rapid fading of the records. In contrast to the 'Acadia' records which, after storage for as much as 14 years, have lost nothing of their clarity, the records from the Mark XIID recorder were liable to fade within a matter of hours, and it thus became essential to ink in the pertinent information as soon as possible. Some few records which were made in 1936, and stored unedited, are now quite illegible. The fading of the Mark XIID records (while the 'Acadia' records remain more or less permanent) is probably attributable to differences in the chemical impregnation and method of wetting in the two instances, the Mark XIID rolls being pre-wetted and supplied in sealed tins. Fading troubles experienced with early pre-wetted paper have since been largely overcome.

The maximum depths for which this set was designed were not achieved by us in practice and it is possible that the thickness of hull plating of the 'Discovery II' had a serious effect in diminishing the strength in both the transmission and reception of the soundwaves.

# APPENDIX II

## PARTICULARS OF RECORDER CHARTS, 1933–1939

*Note.* The abbreviation '(N.C.)' in the remarks column has been used whenever the run was interrupted for any appreciable time (such as for stations or when coming to anchor during a survey); after October 1935 it has also been used to denote those records where charts from both the Acadia and the M/S XIID recorders comprise the run. The time occupied by interruptions has not been included in the totals for the various runs.

| Date | Record No. | Locality | Run in hours | Remarks |
|---|---|---|---|---|
| 22–23. x. 33 | I/33 | 47° 42·7′ N, 06° 18·8′ W to 45° 27·2′ N, 07° 55·5′ W | 12½ | Max. 2600 fm. |
| 23–24. x. 33 | II/33 | 45° 05·9′ N, 08° 45·2′ W to 42° 12·2′ N, 09° 56·5′ W | 12 | — |
| 14. xi. 33 | III/33 | 30° 57·5′ S, 13° 49·5′ W to 31° 17·2′ S, 13° 44·5′ W | 2 | — |
| 15–16. xi. 33 | IV/33 | 36° 07·9′ S, 12° 32′ W to anchorage at Tristan da Cunha | 5¾ | Very steep slope |
| 18. xi. 33 | V/33 | Tristan da Cunha to Nightingale and Inaccessible Islands | 7¼ | Very steep slope |
| 27. xi. 33 | VI/33 | 53° 40·7′ S, 37° 07·3′ W to 54° 03·5′ S, 35° 25′ W | 7 | — |
| 28. xi. 33 | VII/33 | 54° 20·2′ S, 35° 25·2′ W to 54° 22·2′ S, 35° 53·4′ W and approaches to Cumberland Bay, South Georgia | 3 | (N.C.) — |
| 4. xii. 33 | VIII/33 | Sts. 1208–1209–1210 | 4¼ | (N.C.) |
| 9. xii. 33 | IX/33 | 62° 05·5′ S, 59° 21·2′ W to Bransfield Strait, via Nelson Strait | 3¾ | — |
| 9. xii. 33 | X/33 | Approaching Deception Island and through entrance, to anchorage | 1¼ | — |
| 28. xii. 33 | XI/33 | 53° 43·2′ S, 58° 58′ W to 55° 10′ S, 59° 59·2′ W | 10 | — |
| 29. i. 34 | I/34 | Approaching East Cape, North Island, New Zealand | 1½ | — |
| 13. ii. 34 | II/34 | Cook Strait, New Zealand | 2¼ | — |
| 20. viii. 34 | III/34 | Simon's Bay to Cape Town | 4¼ | — |
| 9. ix. 34 | IV/34 | 61° 55′ S, 60° 37′ W to (approx.) 62° S, 61° 30′ W | 3¼ | — |
| 16. ix. 34 | V/34 | 53° 17·5′ S, 75° 45·5′ W to 52° 50′ S, 75° 04′ W | 3¾ | (N.C.) |
| 25–26. ix. 34 | VI/34 | 54° 47·3′ S, 56° 37′ W to 55° 22·9′ S, 56° 04·1′ W | 4¾ | (N.C.) |
| 6. x. 34 | VII/34 | Entrance to Cumberland Bay, South Georgia | 1 | — |
| 9. x. 34 | VIII/34 | South Georgia, Grytviken to Leith Harbour | 1½ | — |
| 10. x. 34 | IX/34 | 53° 40·6′ S, 38° 32·5′ W to 53° 26′ S, 40° 21·8′ W | 8 | Multiple trace |
| 13–14. x. 34 | X/34 | 51° 55′ S, 54° 45′ W to 51° 42·8′ S, 57° 32·5′ W | 10 | — |
| 24–25. x. 34 | XI/34 | Magellan Strait to sea, via Pasa O'Ryan, Ackwalisnan Canal and Cockburn Channel | 10¼ | (N.C.) |
| 19–20. x. 34 | XII/34 } XIII/34 } | 55° 27′ S, 73° 40′ W to Magellan Strait, via Cockburn Channel | 16 | (N.C.) |
| 6. xii. 34 | XIV/34 | 61° 51·3′ S, 61° 50′ W to 63° 07′ S, 62° 55′ W | 8¾ | (N.C.) |
| 6–7. xii. 34 | XV/34 | Schollaert Channel, entrance to Neumayr Channel and return to Melchior Harbour, Palmer Archipelago | 4¼ | Very irregular bottom |
| 7. xii. 34 | XVI/34 | Melchior Harbour to (approx.) 63° 50′ S, 62° 30′ W | 4 | — |
| 8. xii. 34 | XVII/34 | McFarlane Strait, from entrance to Yankee Harbour | 3½ | South Shetlands survey |
| 11. xii. 34 | XVIII/34 | Survey of McFarlane Strait | 6¼ | South Shetlands survey |
| 12. xii. 34 | XIX/34 | McFarlane Strait to English Strait, via Bransfield Strait | 7¾ | South Shetlands survey |
| 13. xii. 34 | XX/34 | English Strait to Yankee Harbour, via Bransfield Strait | 7½ | South Shetlands survey |
| 14. xii. 34 | XXI/34 | Yankee Harbour to Harmony Cove (Nelson Strait), via Bransfield Strait | 5¾ | South Shetlands survey |
| 15–16. xii. 34 | XXII/34 | Harmony Cove to Admiralty Bay | 5½ | South Shetlands survey |
| 17–18. xii. 34 | XXIII/34 | Admiralty Bay to Harmony Cove | 6½ | South Shetlands survey (N.C.) |
| 19. xii. 34 | XXIV/34 | Fildes Strait | 1¾ | South Shetlands survey |
| 19–20. xii. 34 | XXV/34 | Fildes Strait to Admiralty Bay | 3¼ | South Shetlands survey |
| 21. xii. 34 | XXVI/34 | Admiralty Bay to Fildes Strait | 4¾ | South Shetlands survey |

# APPENDIX II (*cont.*)

| Date | Record No. | Locality | Run in hours | Remarks |
|---|---|---|---|---|
| 22–23. xii. 34 | XXVII/34 | Fildes Strait to Deception Island | 12 | South Shetlands survey |
| 26. xii. 34 | XXVIII/34 | Deception Island to Yankee Harbour, via Livingston Island | 10½ | South Shetlands survey |
| 27. xii. 34 | XXIX/34 | Yankee Harbour and McFarlane Strait | 1¼ | South Shetlands survey |
| 30. xii. 34 | XXX/34 | McFarlane Strait to Table Island, via north side Greenwich Island | 6¼ | South Shetlands survey (N.C.) |
| 31. xii. 34 | XXXI/34 | English Strait | ½ | South Shetlands survey |
| 1. i. 35 | I/35 | Coppermine Cove to Harmony Cove, via Bransfield Strait | 8 | South Shetlands survey |
| 2. i. 35 | II/35 | Harmony Cove to north side, King George Island | 3½ | South Shetlands survey |
| 3. i. 35 | III/35 | North side, King George Island | 5¾ | South Shetlands survey (N.C.) |
| 4. i. 35 | IV/35 | North side, King George Island to Harmony Cove | 3¼ | South Shetlands survey |
| 5. i. 35 | V/35 | Harmony Cove to north side, Greenwich Island | 8 | South Shetlands survey |
| 6. i. 35 | VI/35 | North side, Greenwich Island | 1 | South Shetlands survey |
| 6. i. 35 | VII/35 | North end, McFarlane Strait to Desolation Island | 1½ | South Shetlands survey |
| 7. i. 35 | VIII/35 | From Desolation Island along north side, Livingston Island | 6½ | South Shetlands survey |
| 8. i. 35 | IX/35 | North side, Livingston Island to Desolation Island | 3¼ | South Shetlands survey |
| 9. i. 35 | X/35 | Desolation Island to Deception Island, via north side Livingston Island | 10½ | South Shetlands survey |
| 11. i. 35 | XI/35 | De Gerlache Strait | ¾ | — |
| 19. i. 35 | XII/35 | Port Lockroy—Peltier Channel—De Gerlache Strait | 7¼ | — |
| 20. i. 35 | XIII/35 | Approaching Cape Roquemarel, Trinity Peninsula | 1½ | — |
| 20. i. 35 | XIV/35 | Cape Roquemarel to Astrolabe Island | 3¾ | — |
| 20. i. 35 | XV/35 | Leaving Astrolabe Island | 1¼ | — |
| 21. i. 35 | XVI/35 | Passing Bridgeman Island | ¾ | — |
| 10. ii. 35 | XVII/35 | Douglas Strait, South Sandwich Islands | 1¼ | Submarine crater |
| 7. iv. 35 | XVIII/35 | Marion and Prince Edward Islands | 10 | — |
| 23. iv. 35 | XIX/35 | 22° 31·2′ S, 40° 25·7′ E to 22° 17·6′ S, 40° 28·8′ E | 1¾ | Near Europa Island |
| 23–24. iv. 35 | XX/35 | 18° 12′ S, 41° 41·1′ E to 17° 52′ S, 41° 44·2′ E | 2 | Mozambique Channel |
| 5. v. 35 | XXI/35 | Off Cape Gardafui | 3 | (N.C.) |
| 7–8. v. 35 | XXII/35 | 12° 54′ N, 43° 17′ E to 13° 37′ N, 42° 59′ E | 4 | Red Sea |
| 8. v. 35 | XXIII/35 | Zubair Islands | 1 | Red Sea |
| 8. v. 35 | XXIV/35 | Jebal At Tair | 1 | Red Sea |
| 11. v. 35 | XXV/35 | Daedalus Reef | 1 | Red Sea |
| 11. v. 35 | XXVI/35 | The Brothers | 1¼ | Red Sea |
| 11–12. v. 35 | XXVII/35 | Straits of Jubal and Gulf of Suez | 2¼ | Red Sea |
| 19. v. 35 | XXVIII/35 | Malta Channel | 1¾ | — |
| 20. v. 35 | XXIX/35 | Passing Cape Bon, Mediterranean | 1 | — |
| 20. v. 35 | XXX/35 | Passing Cani Rocks, Mediterranean | 2 | — |
| 20. v. 35 | XXXI/35 | Passing Pantellaria, Mediterranean | 2 | — |
| 29. v. 35 | XXXII/35 | Approaching Cape St Vincent | 2 | — |
| 30. v. 35 | XXXIII/35 | Off Cape Espichel | 1¼ | — |
| 30. v. 35 | XXXIV/35 | Passing The Burlings | 2½ | — |
| 5. x. 35 | XXXV/35 | Across Hurd Deep | 2 | Near Channel Islands |
| 10. x. 35 | XXXVI/35 | South from Ushant | 2¼ | — |
| 10. x. 35 | XXXVII/35 | North Coast of Spain | 5¼ | — |
| 10. x. 35 | XXXVIII/35 | Dacia Bank | 3 | — |
| 28. xi. 35 | XXXIX/35 to XL/35 | Across Kerguelen-Gaussberg Ridge | 7½ | (N.C.) |
| 30. xii. 35 | XLI/35 | Approaching Foveaux Strait, New Zealand | 3¼ | — |
| 30–31. xii. 35 | XLII/35 | Foveaux Strait | 10 | — |
| 10. i. 36 | I/36 | 70° 55′ S, 178° 19·4′ W to 70° 59·7′ S, 178° 10′ W | 1 | Re-echoes |
| 14. i. 36 | II/36 to III/36 | 72° 30·2′ S, 178° 03·2′ W to 73° 08·4′ S, 179° 52′ W | 4 | — |
| 14. i. 36 | IV/36 | 74° 17·1′ S, 179° 18·5′ E to 74° 44·8′ S, 179° 55′ E | 3 | — |

## APPENDIX II (*cont.*)

| Date | Record No. | Locality | Run in hours | Remarks |
|---|---|---|---|---|
| 16. i. 36 | V/36 \ VI/36 / | 78° 00·9′ S, 169° 04′ W to 78° 26′ S, 164° 11′ W | 2 | — |
| 25. i. 36 | VII/36 | Off Ross Island | 4¾ | (N.C.) |
| 26. i. 36 | VIII/36 | 75° 39·2′ S, 173° 50′ E to 75° 22·3′ S, 176° 18·5′ E | 4 | — |
| 2. ii. 36 | IX/36 | From approx. 66° 01′ S, 164° 45′ E towards Balleny Islands | 3¾ | Remainder undecipherable |
| 3. ii. 36 | X/36 | Approaching the Balleny Islands | 3¼ | — |
| 3. ii. 36 | XI/36 | Leaving the Balleny Islands | ¾ | — |
| 5. ii. 36 | XII/36 | 65° 32·9′ S, 160° 54·4′ E to 65° 14·7′ S, 160° 55·8′ E | 1¾ | — |
| 18. v. 36 | XIII/36 | 33° 50·5′ S, 17° 28′ E to 33° 50·4′ S, 17° 10·7′ E | 1¾ | — |
| 19. v. 36 | XIV/36 | 33° 50·5′ S, 14° 59·4′ E to 33° 50·4′ S, 14° 43·1′ E | 1 | 2700 fm. |
| 20. v. 36 | XV/36 | 33° 42·5′ S, 10° 25′ E to 33° 41·6′ S, 10° 02·2′ E | 2 | 2700 fm. |
| 17. ix. 36 | XVI/36 | 33° 54·4′ S, 11° 15·3′ E to 33° 54·3′ S, 11° 12·5′ E | ¼ | 2600 fm. |
| 19. ix. 36 | XVII/36 | 33° 41·5′ S, 02° 12′ E to 33° 39·2′ S, 01° 29·9′ E | 3½ | (N.C.) |
| 14. x. 36 | XVIII/36 | 54° 20·9′ S, 35° 16′ W to 54° 27·6′ S, 35° 45·4′ W thence toward Cumberland Bay | 9½ | (N.C.). courses various approaching South Georgia |
| 23. x. 36 | XIX/36 | Approaching Willis Island, South Georgia | 4½ | (N.C.) |
| 12–13. xi. 36 | XX/36 | 64° 01·4′ S, 53° 13·3′ W to 61° 20·8′ S, 54° 04·2′ W | 17¼ | (N.C.) |
| 5. xii. 36 | XXI/36 | Approaching South Georgia from Port Stanley | 6½ | — |
| 18. xii. 36 | XXII/36 | Round Willis Island to Undine Harbour, South Georgia | 6¾ | (N.C.) |
| 19. xii. 36 | XXIII/36 | Undine Harbour to Bird Island, South Georgia | 3 | — |
| 5. i. 37 | I/37 | Bridgeman Island to North Foreland, King George Island | 3½ | (N.C.) South Shetlands survey |
| 6. i. 37 | II/37 | North Foreland to Penguin Island anchorage | 4¼ | (N.C.) South Shetlands survey |
| 7. i. 37 | III/37 | Penguin Island to Lion's Rump, via Admiralty Bay | 6 | (N.C.) South Shetlands survey |
| 9. i. 37 | IV/37 | Lion's Rump to Penguin Island | ¾ | South Shetlands survey |
| 10. i. 37 | V/37 | Penguin Island to Lion's Rump | ¾ | South Shetlands survey |
| 11. i. 37 | VI/37 | Lion's Rump to Penguin Island | 2 | St. 1952 intervenes. South Shetlands survey |
| 12. i. 37 | VII/37 | Penguin Island to Lion's Rump | ¾ | South Shetlands survey |
| 13. i. 37 | VIII/37 | Lion's Rump—Cape Melville—Lion's Rump | 5 | (N.C.) South Shetlands survey |
| 14–15. i. 37 | IX/37 | Penguin Island to anchorage near Esther Harbour | 8¼ | (N.C.) South Shetlands survey |
| 15. i. 37 | X/37 | Anchorage to Esther Harbour | 1¾ | South Shetlands survey |
| 18. i. 37 | XI/37 | North Foreland—Bolinder Beach and to sea | 7¼ | (N.C.) South Shetlands survey |
| 19. i. 37 | XII/37 | Towards anchorage, Penguin Island | 5½ | South Shetlands survey |
| 20. i. 37 | XIII/37 | Penguin Island to Visca anchorage, Admiralty Bay | 4 | South Shetlands survey |
| 22. i. 37 | XIV/37 | Visca Anchorage to North Foreland | 10¾ | South Shetlands survey |
| 23. i. 37 | XV/37 | North Foreland to sea and hove-to | 1½ | South Shetlands survey |
| 25. i. 37 | XVI/37 | Cape Melville to Admiralty Bay | 6½ | South Shetlands survey |
| 28. i. 37 | XVII/37 | From approx. 61° 35′ S, 57° 23′ W | 6½ | (N.C.) See ship's log |
| 30. i. 37 | XVIII/37 | Ridley Island to O'Brien Island | 12 | (N.C.) |
| 31. i. 37 | XIX/37 | O'Brien Island—Gibbs Island—Aspland Island | 9¾ | — |
| 1. ii. 37 | XX/37 | Off Gibbs and Aspland Islands, on survey | 8 | — |
| 2. ii. 37 | XXI/37 | Off Gibbs Island and to Clarence Island | 9 | (N.C.) |
| 4. ii. 37 | XXII/37 | Clarence Island to Cornwallis Island | 5½ | (N.C.) |
| 6. ii. 37 | XXIII/37 | Approaching South Orkneys | 4¾ | See note on record re berg |
| 11. ii. 37 | XXIV/37 | Scotia Bay to Graptolite Island | 4 | South Orkneys survey |

# APPENDIX II (*cont.*)

| Date | Record No. | Locality | Run in hours | Remarks |
|---|---|---|---|---|
| 12. ii. 37 | XXV/37 | Graptolite Island to Signy Island | 13 | South Orkneys survey |
| 13. ii. 37 | XXVI/37 | Approaching and leaving Borge Bay | 4¾ | (N.C.) South Orkneys survey |
| 14. ii. 37 | XXVII/37 | Approaching Sandefjord Bay | 2 | South Orkneys survey |
| 15. ii. 37 | XXVIII/37 | Sandefjord Bay to North Coast Coronation Island | 5½ | (N.C.) South Orkneys survey. Very steep slope |
| 21–22. iv. 37 | XXIX/37 | 32° 53′ S, 00° 06·4′ W to 32° 02·2′ S, 00° 22·2′ W | 4 | Shallow ridge |
| 13. x. 37 | XXX/37 | Josephine Bank | 4¼ | — |
| 14. x. 37 | XXXI/37 | Approaching Madeira | 2 | — |
| 19. x. 37 | XXXII/37 | Approaching St Vincent | 1¾ | — |
| 1. xi. 37 | XXXIII/37 | Approx. 18° S, 3° E | 1 | (N.C.) 3000 fm. |
| 3. xi. 37 | XXXIV/37 | Approx. 24° S, 9° E | 1 | 2600 fm. |
| 4. xi. 37 | XXXV/37 | Approx. 28° S, 12° E | 1¼ | 2600 fm. |
| 5. xi. 37 | XXXVI/37 | 29° 05·2′ S, 13° 32·4′ E to 29° 34·5′ S, 14° 03′ E | 4¼ | — |
| 29. xi. 37 | XXXVII/37 | 57° 59·5′ S, 56° 00·8′ E to 58° 14·1′ S, 56° 43·1′ E | 3 | 2900 fm. |
| 30. xi. 37 | XXXVIII/37 | 59° 31·2′ S, 60° 42·3′ E to 59° 42·3′ S, 61° 13·5′ E | 2½ | 2900 fm. |
| 1. xii. 37 | XXXIX/37 | 60° 06·4′ S, 66° 17·3′ E to 60° 07·6′ S, 66° 58·5′ E | 2¼ | 2600 fm. |
| 3. xii. 37 | XL/37 | 57° 26·6′ S, 74° 06·7′ E to 56° 18·2′ S, 76° 30·4′ E | 12½ | Kerguelen-Gaussberg Ridge |
| 3–4. xii. 37 | XLI/37<br>XLII/37 | 56° 13·7′ S, 76° 39·2′ E to 56° 56·5′ S, 80° 28·7′ E | 22 | Kerguelen-Gaussberg Ridge: courses various, see ship's log |
| 18–19. xii. 37 | XLIII/37 | Approaching Fremantle, West Australia | 2¾ | — |
| 30. xii. 37 | XLIV/37 | 34° 25′ S, 114° 35′ E to 35° 15·3′ S, 114° 45′ E | 6 | — |
| 14. i. 38 | I/38 | 61° 51·1′ S, 131° 04·6′ E to 61° 58·1′ S, 131° 18·8′ E | 1¼ | 2400 fm. |
| 15–16. i. 38 | II/38 | 63° 53·1′ S, 135° 16·8′ E to 66° 13·8′ S, 139° 46·4′ E | 23 | (N.C.) |
| 16. i. 38 | III/38 | 66° 14′ S, 139° 50′ E to 65° 18′ S, 139° 10·6′ E | 5 | — |
| 19. i. 38 | IV/38 | 64° 15·6′ S, 153° 58′ E to 64° 26·7′ S, 154° 14·7′ E | 1½ | — |
| 19. i. 38 | V/38 | 66° 06·8′ S, 156° 42·2′ E to 66° 55·6′ S, 157° 59·5′ E | 6 | — |
| 20–21. i. 38 | VI/38 | Balleny Islands | 9½ | See Text-fig. (N.C.) |
| 21–22. i. 38 | VII/38 | Balleny Islands | 13¾ | See Text-fig. |
| 26–27. i. 38 | VIII/38 | 54° 59·3′ S, 167° 54·2′ E to 53° 46·2′ S, 168° 41·2′ E | 9 | — |
| 27–28. i. 38 | IX/38 | 52° 59·2′ S, 169° 00′ E to Campbell Island | 7½ | Includes harbour (N.C.) |
| 7–8. ii. 38 | X/38 | Dunedin (N.Z.) to 46° 03·2′ S, 171° 22·5′ E | 4 | — |
| 9–10. ii. 38 | XI/38 | Antipodes Island | 4½ | Circuit of island |
| 26. ii. 38 | XII/38 | 69° 11·8′ S, 123° 26·7′ W | ½ | Shallow soundings |
| 14. iii. 38 | XIII/38 | 55° 35′ S, 60° 14′ W to 54° 44·8′ S, 59° 36·8′ W | 4 | Burdwood Bank |
| 28. iii. 38 | XIV/38 | 55° 32·1′ S, 36° 07·4′ W to South Georgia | 3¼ | — |
| 19. iv. 38 | XV/38 | 64° 47·3′ S, 07° 37·8′ E to 64° 48·5′ S, 08° 02·1′ E | 1 | 2400 fm. |
| 7. vii. 38 | XVI/38 | 41° 54·2′ S, 01° 17′ E to 42° 20·1′ S, 01° 18·7′ E | 2½ | Discovery Bank |
| 10. vii. 38 | XVII/38 | 50° 53·1′ S, 00° 27·7′ E to 51° 02·2′ S, 00° 26·4′ E | 1 | Shallow soundings |
| 25. vii. 38 | XVIII/38 | 41° 25·2′ S, 19° 32·2′ E to 41° 09·6′ S, 19° 27·9′ E | 1½ | 2900–2700 fm. |
| 11. viii. 38 | XIX/38 | 41° 52·1′ S, 00° 18·2′ E to 42° 19·3′ S, 00° 17·8′ E | 3 | Discovery Bank |
| 16. viii. 38 | XX/38 | 54° 30′ S, 00° 15·7′ E to 54° 50·3′ S, 00° 17·4′ E | 2 | Shallow soundings |
| 20. ix. 38 | XXI/38 | 41° 57′ S, 00° 38′ E to 42° 12·7′ S, 00° 39′ E | 1½ | Discovery Bank |
| 23. x. 38 | XXII/38 | 41° 50·5′ S, 01° 17·4′ E to 42° 09·9′ S, 01° 20·5′ E | 3 | (N.C.) Discovery Bank |
| 28. x. 38 | XXIV/38 | 54° 58·8′ S, 02° 14·9′ E to 54° 45·8′ S, 02° 33·4′ E | 2¾ | Bouvet Island |
| 28. x. 38 | XXV/38 | 54° 38·4′ S, 02° 39·9′ E to 54° 19′ S, 03° 25′ E | 4 | (N.C.) Bouvet Island |
| 29. xi. 38 | XXVI/38 | 42° 02·6′ S, 00° 55·4′ W to 42° 04·9′ S, 00° 48·6′ E | 9 | Discovery Bank (W to E) |
| 9. i. 39 | I/39 | 35° 58·8′ S, 11° 42·5′ E to 36° 08·3′ S, 11° 13·4′ E | 2½ | 2700 fm. |
| 17. i. 39 | II/39 | Bouvet Island | 4 | (N.C.) |
| 21–22. i. 39 | III/39 | 68° 50·2′ S, 02° 05·4′ E to 69° 37·9′ S, 02° 07·8′ E | 4½ | (N.C.) Approaching Continental Shelf |
| 29. i. 39 | IV/39 | 62° 33·9′ S, 19° 43·3′ E to 62° 24·3′ S, 19° 44·1′ E | 1 | 2700 fm. |
| 21. ii. 39 | V/39 | 41° 40·8′ S, 00° 48·2′ E to 42° 31·7′ S, 00° 50′ E | 5½ | Discovery Bank |
| 24. ii. 39 | VI/39 | 51° 07·6′ S, 01° 06′ E to 51° 17′ S, 01° 06′ E<br>51° 35′ S, 01° 04·4′ E to 51° 43·1′ S, 01° 03·7′ E | 1<br>1 | Shallow soundings |
| 4. iii. 39 | VII/39 | 69° 14·8′ S, 00° 18·2′ E to Barrier and thence along coast of continent to 69° 47·8′ S, 02° 21·1′ E | 15 | Courses various, see sounding log for details |
| 5. iii. 39 | VIII/39 | Continuing along coast of continent | 13 | |

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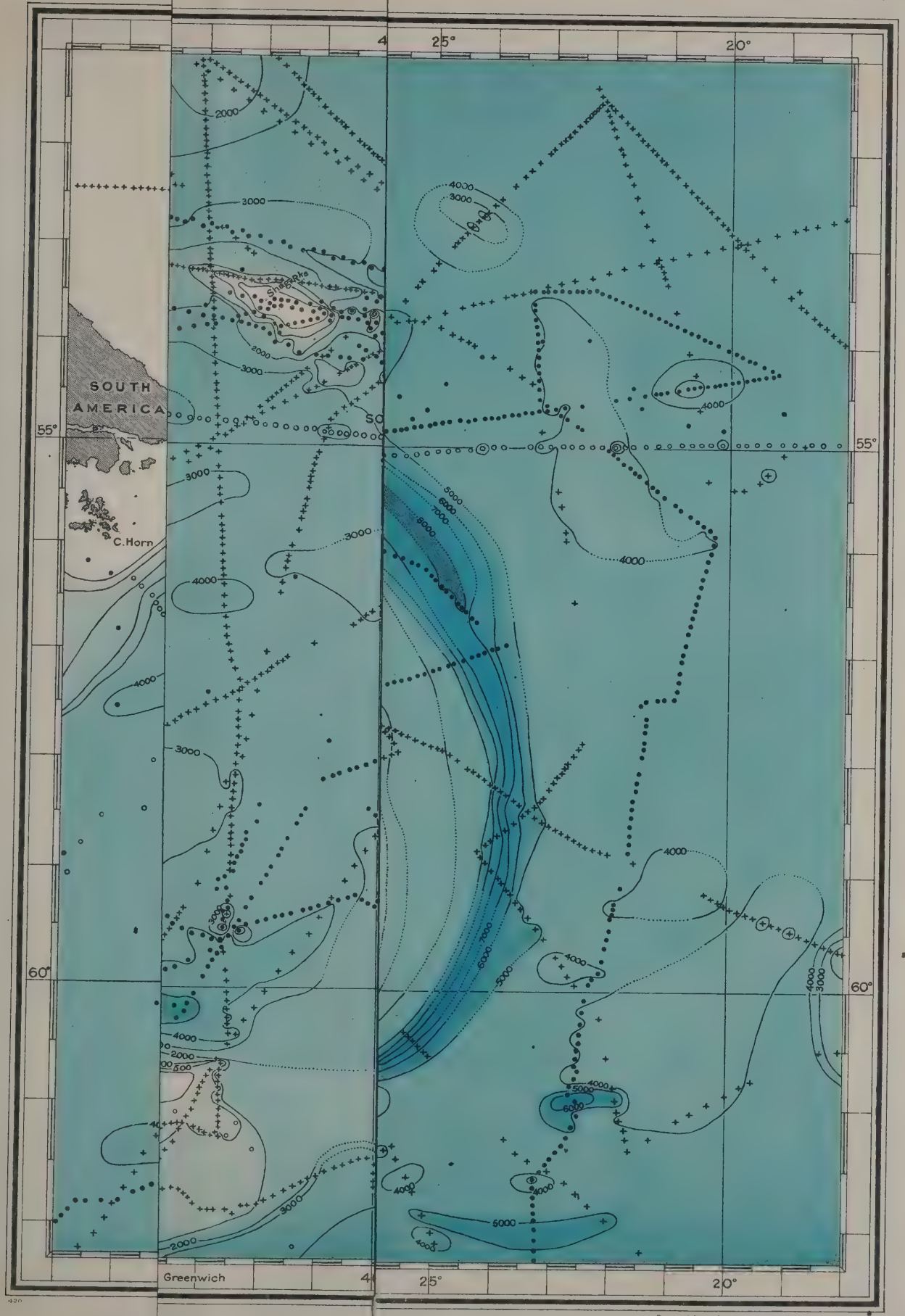
## NOTE ON THE PLATES

Plates XXVI–XXXI are collotype reproductions of selected sections of sounding records, all reduced to one-half the original size. The order of sounding is from left to right. In colour and intensity they approximate to the originals, which vary a little in these respects. Reproduction has involved a slight loss of contrast but virtually no loss of detail. Even where the line of the sea floor becomes confused and lost, almost no details can be seen in the originals which cannot be seen in the collotypes.




SCOTIA SEA

*by the Discovery Investigat*
*ositions of those taken subse*
*om other sources are shown*

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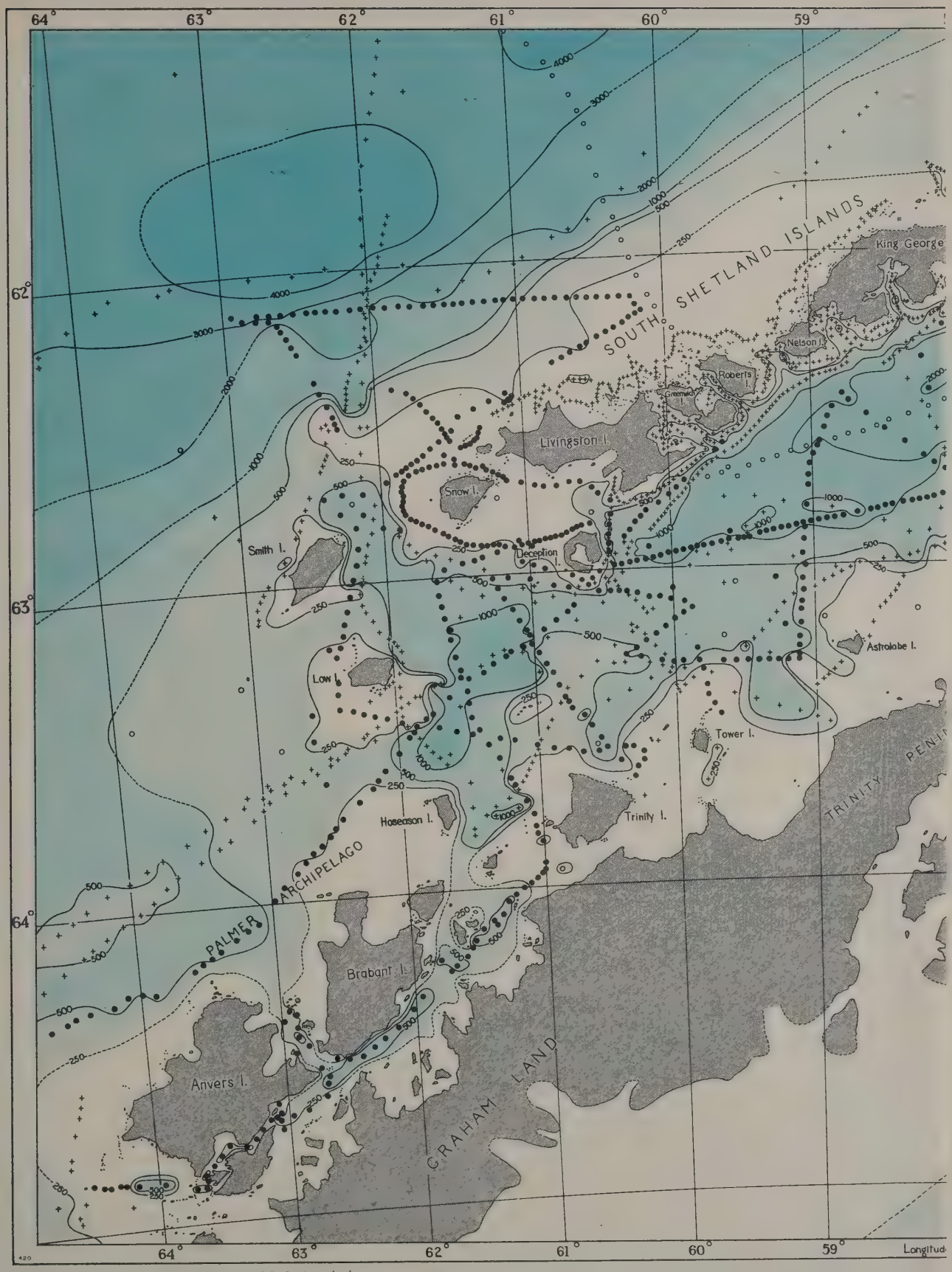


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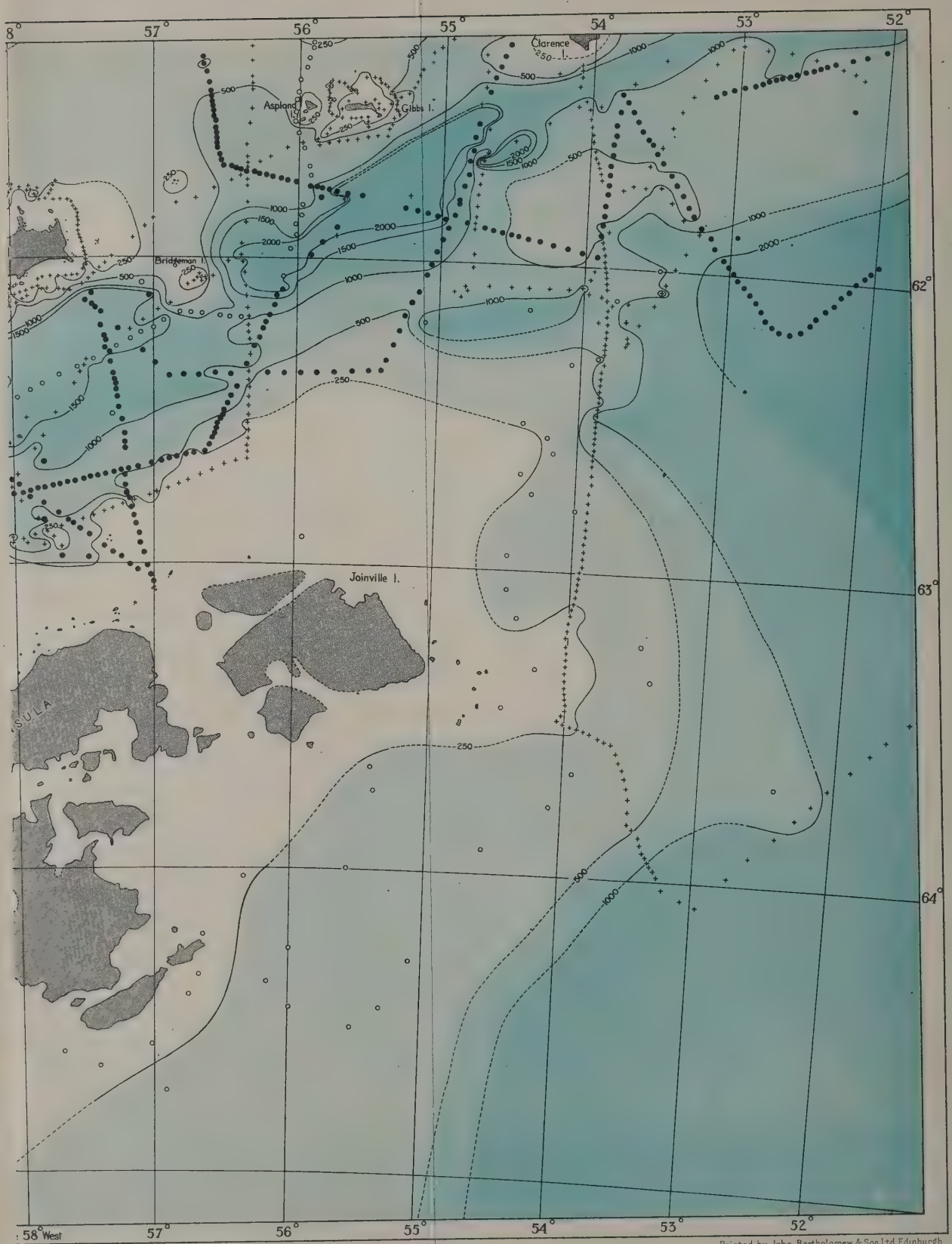
## THE BRANSFIELD STRAI

*The positions of soundings taken by t*
*1932, are shown as black dots ; the positi*
*with crosses. Soundings from*

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## T AND ADJACENT WATERS

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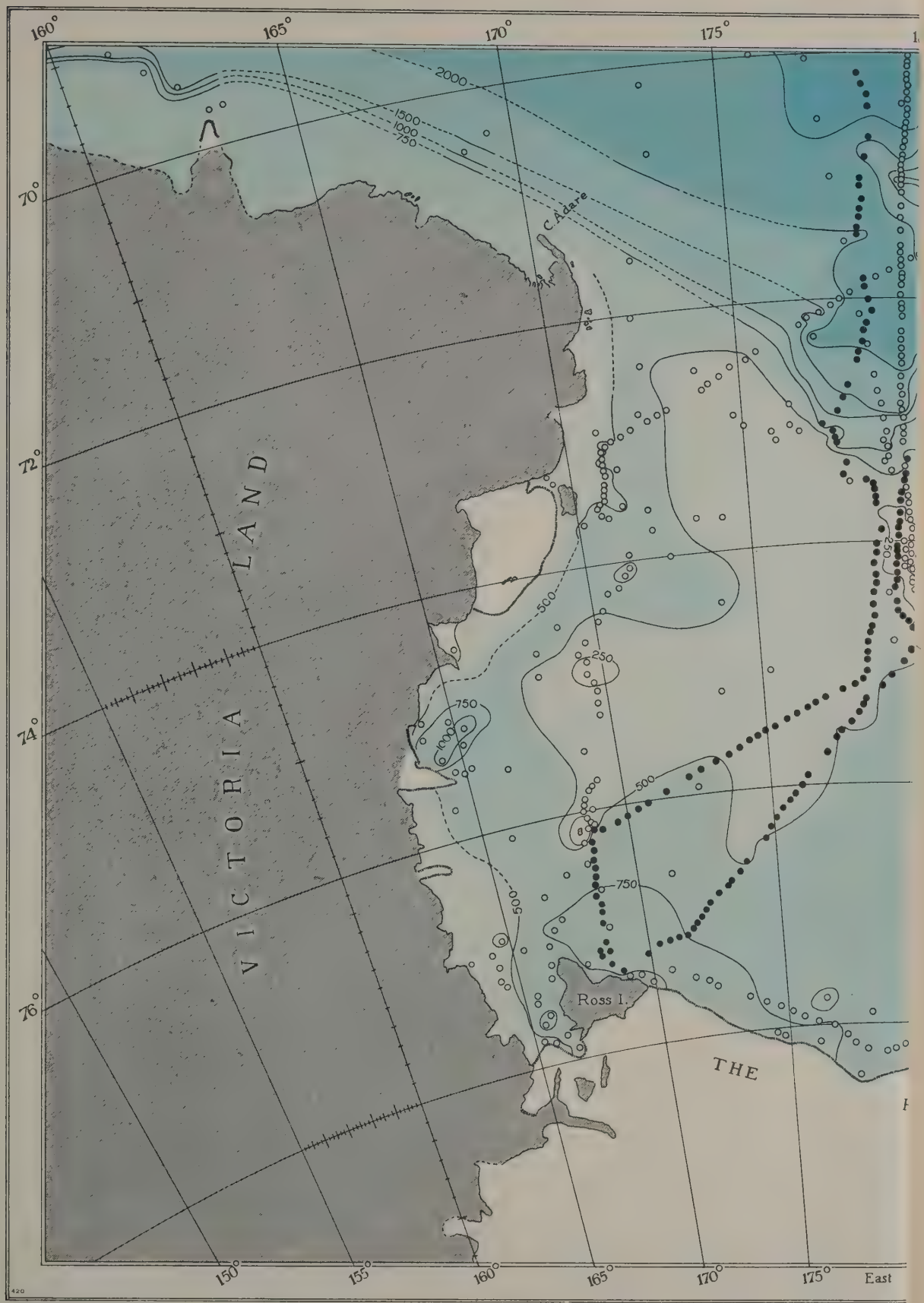
*ons of those taken subsequently are marked*
*ther sources are shown as circles.*

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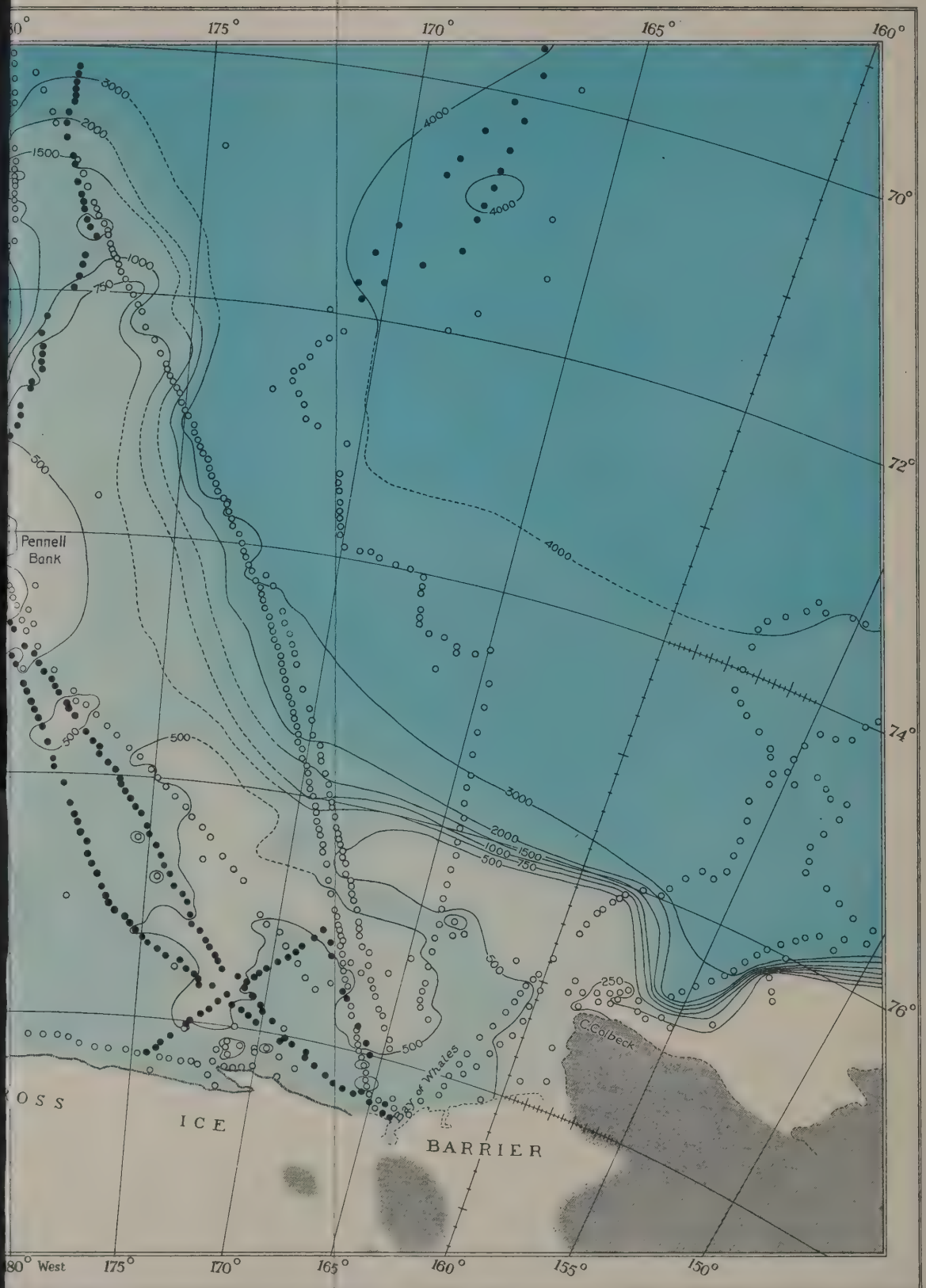
*The positions of soundings taken by th*
*black. Soundings from other*

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OSS SEA

*e Discovery Investigations are shown in*
*sources are shown as circles.*

# PLATE XXVI

Fig. 1. Slope of bottom north from Coronation Island, South Orkneys. Phasing by 100 fathom steps. Speed of ship, 9 knots. Vertical scale, × 9·72. From 60° 26′ S, 45° 55·5′ W to 60° 21·5′ S, 45° 59·3′ W. (Part of Record XXVIII/37.) See Text-figs. 3 (*c*), p. 46, and 13, p. 66.

Fig. 2. Slope of bottom approaching Falmouth Bay, Tristan da Cunha, from the North. Phasing by 200 fathom steps. Speed of ship, 9·5 knots. Vertical scale, × 10·26. From 36° 56·8′ S, 12° 19·3′ W to anchorage at Falmouth Bay. (Part of Record IV/33.) See Text-figs. 3 (*a*), p. 46, and 9, p. 55.

Fig. 3. Approaching Antarctica in the meridian of Greenwich; confused bottom at 900 to 1000 fm. (1646 to 1829 m.), followed by a steady rise to a depth of 170 fm. (311 m.) close to land. Virtually no continental shelf. Speed of ship, 9 knots. Vertical scale, × 9·72. From 69° 37·4′ S, 00° 41′ E to 69° 43·6′ S, 00° 50·3′ E. (Part of Record VII/39.) See Text-figs. 2 (*a*), p. 45, and 17, p. 88.

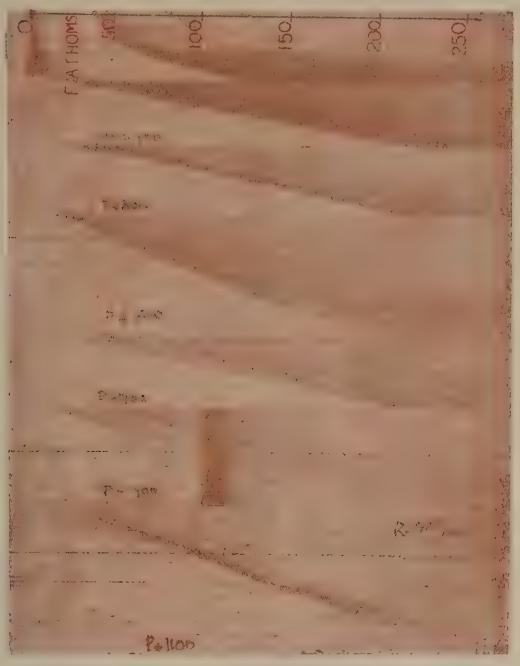


Fig. 2

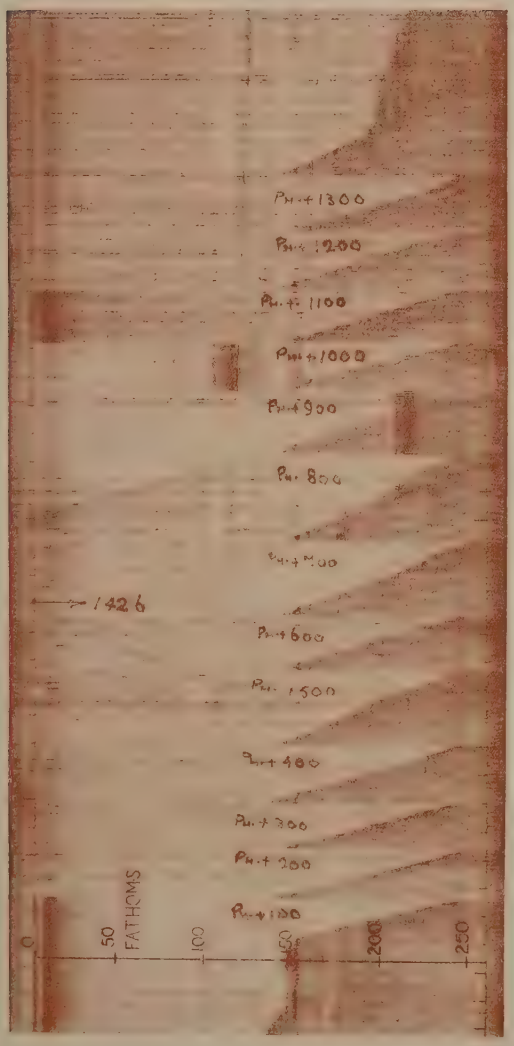


Fig. 1

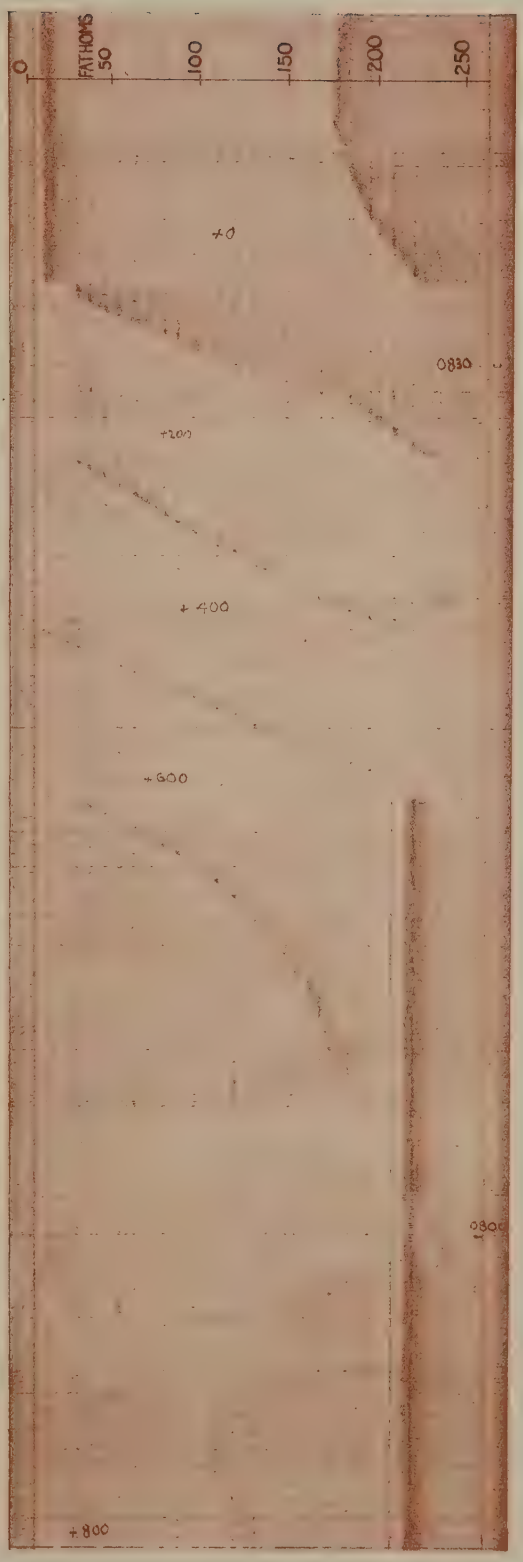


Fig. 3

## PLATE XXVII

Fig. 1. Varied bottom, at depths between 125 and 340 fm. (229 and 622 m.) in the Schollaert Channel, Palmer Archipelago. Speed of ship shown on record. Vertical scales: at 3 knots, × 3·24; at 9 knots, × 9·72. Note interference to the mains supply caused by induced current from ship's W/T apparatus. (Part of Record XV/34.)

Fig. 2. Moderately irregular bottom in the Bransfield Strait, South Shetlands, on a course from Fildes Strait to Deception Island. Section of record shown lies about 4 miles south-east of the coast of Roberts Island. Speed of ship, *ca.* 3·5 knots. Vertical scale, × *ca.* 3·8. (Part of Record XXVII/34.) See Text-fig. 4 (*b*), p. 47.

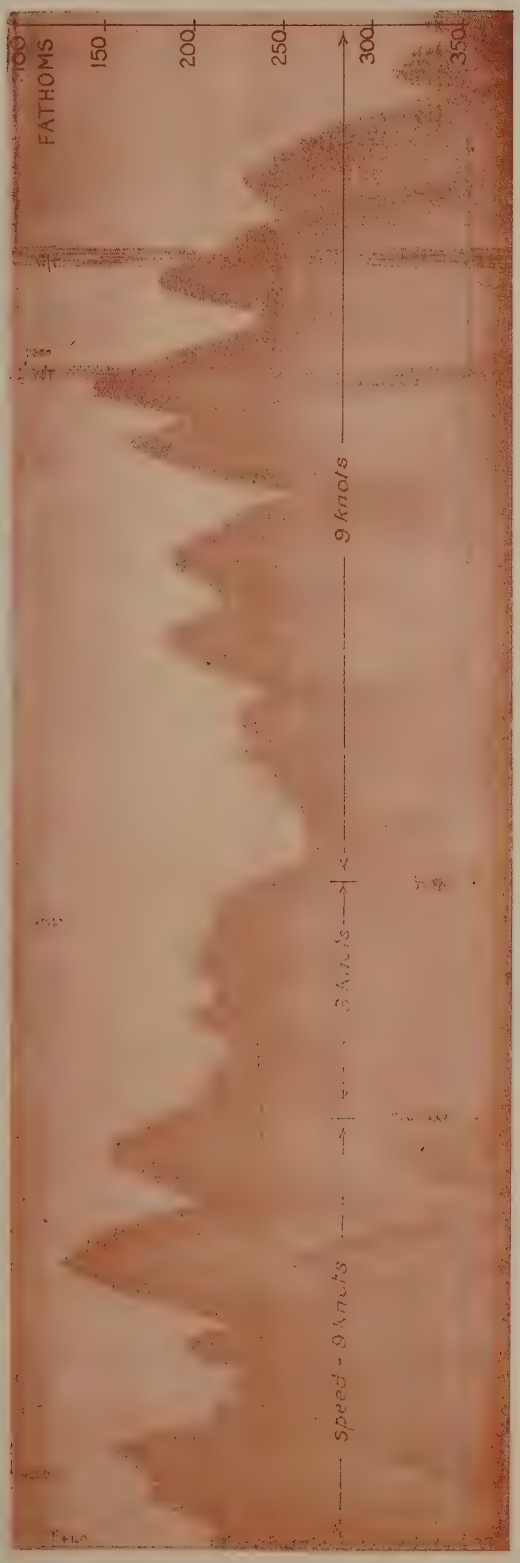
FATHOMS
100
150
200
250
300
350
Speed - 9 knots
9 knots

Fig. 1

FATHOMS
100
150
200
250
300

Fig. 2

# PLATE XXVIII

Fig. 1. Approaching Adélie Land from the north-west. This recording shows the complicated structure of the bottom at depths between 1170 and 1320 fm. (2140 and 2414 m.), at the point where the steeper slope up to the continental shelf begins. Speed of ship, 9·5 knots. Vertical scale, × 10·26. From 64° 56′ S, 137° 38′ E to 65° 04′ S, 137° 50′ E. (Part of Record II/38.) See Text-figs. 1 (*b*), p. 44, and 17, p. 88.

Fig. 2. Complicated slope from coastal shelf to deeper water, off Otago Harbour, New Zealand. Record begins at 230 fm. (421 m.), on change over from shallow water set and records a maximum depth of 600 fm. (1097 m.). Speed of ship, 9·65 knots. Vertical scale, × 10·42. From 45° 50·4′ S, 171° 04·4′ E to 45° 58·2′ S, 171° 13′ E. (Part of Record X/38.) See Text-fig. 2 (*b*), p. 45.

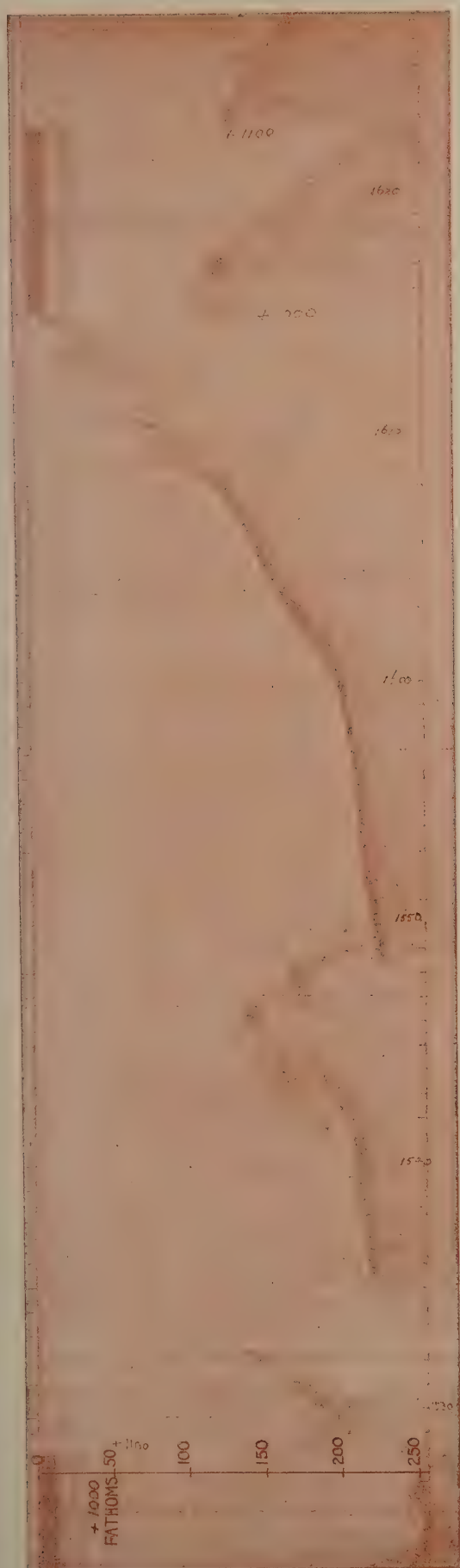
+ 1100
1620
+ 200
1600
1700
1550
1540
1730
+ 1100
FATHOMS
0
50
100
150
200
250

Fig. 1

+ 400
0260
0250
0240
0230
0220
0210
+ 200
+ 100
FATHOMS
0
50
100
150
200
250
0205

Fig. 2

# PLATE XXIX

Fig. 1. Extremely irregular bottom recorded when approaching Bouvet Island from the south-west. Speed of ship, 10 knots. Vertical scale, × 10·8. From 54° 33·4′ S, 02° 50·3′ E to 54° 27·1′ S, 03° 04′ E. (Part of Record XXV/38.) See Text-fig. 2 (*a*), p. 45.

This is a typical example of the difficulties met in obtaining echo soundings from moderate depths on the line between the latitude of 40° S and the ice-edge, on the meridian of Greenwich. On this occasion conditions were good since the sea was calm, wind only force 2 and there was little swell.

Fig. 2. Irregular bottom at depths varying between 1220 and 1450 fm. (2231 and 2652 m.) on the outer slope of the Scotia Arc, 75 miles NW × W of Bird Island, South Georgia. Speed of ship, 8 knots. Vertical scale, × 8·64. From 53° 59′ S, 39° 54′ W to 53° 28·3′ S, 40° 00·8′ W. (Part of Record IX/34.) See Text-fig. 5(*b*), p. 49.

Fig. 3. Passing Europa Island, Mozambique Channel. Irregular bottom and moderate slope. Soundings range between 406 and 1000 fm. (742 and 1829 m.). Speed of ship, 8·8 knots. Vertical scale, × 9·5. From 22° 24·7′ S, 40° 26·8′ E to 22° 18·2′ S, 40° 28·8′ E. (Part of Record XIX/35.)

Fig. 1

Fig. 2

Fig. 3

between 890 and 1000 fm. (1638 and 1824 m.) during the survey
of Clarence Island. Speed of ship, ca. 4·5 knots. Vertical scale,
× ca. 4·9. (Part of Record XXVIII/37.) See Text-fig. 3 (c), p. 46.

# PLATE XXX

Fig. 1. Passage from open water through brash ice and loose pack, off the ice barrier in Long. 1° E. Sea, calm; wind, force 2. Speed of ship, 9 knots. Vertical scale, ×9·72. In loose pack the echo, even at this shallow depth, is almost obliterated by the noises set up by the scraping of ice across the face of the hydrophone. This record shows part of the sea floor which is relatively free from irregularities. Position (at 1030 hr.) 69° 50·2′S, 00° 56·7′ E. (Part of Record VII/39.) See Text-fig. 2 (*a*), p. 45.

Fig. 2. Re-echoes at 1780–2000 fm. (3255–3658 m.) from soundings between 890 and 1000 fm. (1628 and 1829 m.) during the survey of Clarence Island. Speed of ship, *ca.* 4·5 knots. Vertical scale, ×*ca.* 4·9. (Part of Record XXVIII/37.) See Text-fig. 3 (*c*), p. 46.

Fig. 3. Section of record showing the effect of a rising wind and sea on the echo, at a depth of approximately 270 fm. (494 m.), on the Discovery Bank. Section begins with recording at a speed of ship of 2 knots, which increases to 8·5 knots at the point indicated. Wind was NW, 22–27 knots and sea, NW, force 5; there was also a moderate North-westerly swell. Ship's course, W. Weather was deteriorating rapidly. Vertical scales: at 2 knots, ×2·16; at 8·5 knots, ×9·18. From 42° 03·9′ S, 00° 03·5′ E to 42° 04·1′ S, 00° 11′ E. (Part of Record XXVI/38.) See Text-fig. 2 (*a*), p. 45.

Fig. 4. Simple 'crossover' at a depth of 215 fm. (393 m.). Speed of ship, 9·5 knots. Vertical scale, ×10·26. Position, approx., 14 miles N 63° W of C. Finisterre.

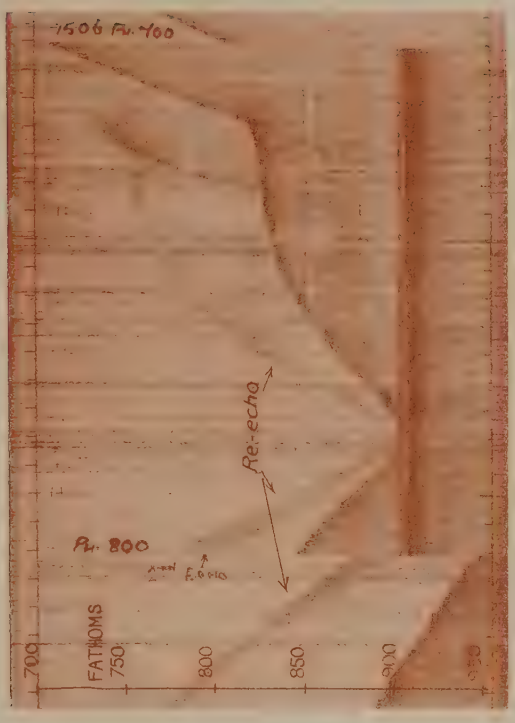


Fig. 2

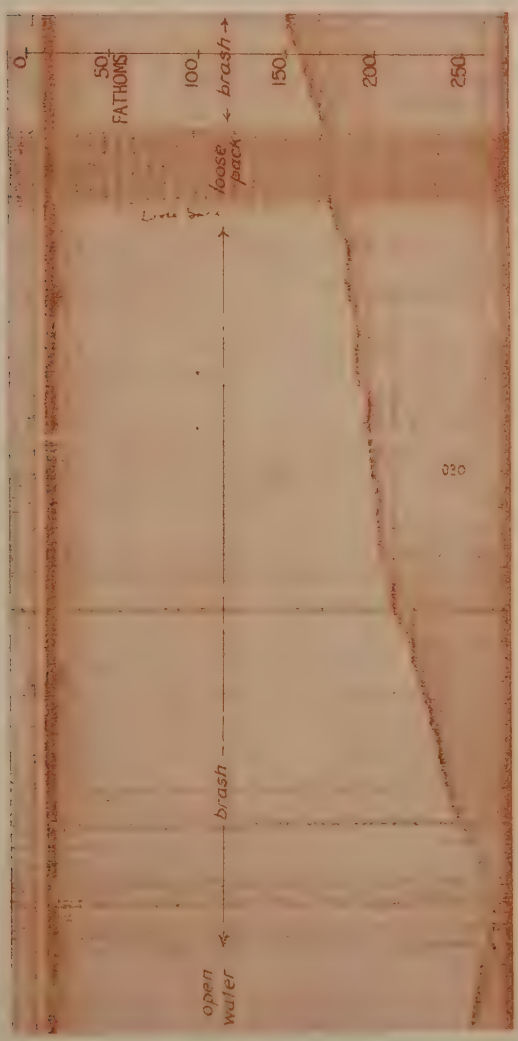


Fig. 1

Fig. 4

Fig. 3

# PLATE XXXI

Fig. 1. Example of the elimination of the transmission band, by means of the 'cut-out' switch, to allow the echo to be recorded at depths varying between 990 and 1210 fm. (1810 and 2213 m.). In this instance a fault in the transmission, known as 'double-knocking', also is seen recorded. This trouble normally was caused by the lack of sufficient 'back-pressure' through the reducing valve, which prevented the sharp return of the hammer to the magnetic valve. It could also be caused by the partial failure of the magnetic air valve in the head of the hammer, when a second blow would be struck before the supply of H.P. air was properly cut off. Speed of ship, 10 knots. Vertical scale. × 10·8. (Part of Record XXXVI/37.)

Fig. 2. Typical record from M/S. XII type shallow water recorder. Record made during survey of NW coast of Coronation Island, South Orkneys, in 1937. Pencil markings were inserted as soon as the record was dry, in order to facilitate the plotting of the soundings should the record fade. Time scale automatically marked every 3 minutes. Speed of ship, 7 knots. Vertical scale, × 7·56. (Part of Record XXVIII/37.) See Text-fig. 3(*c*), p. 46.

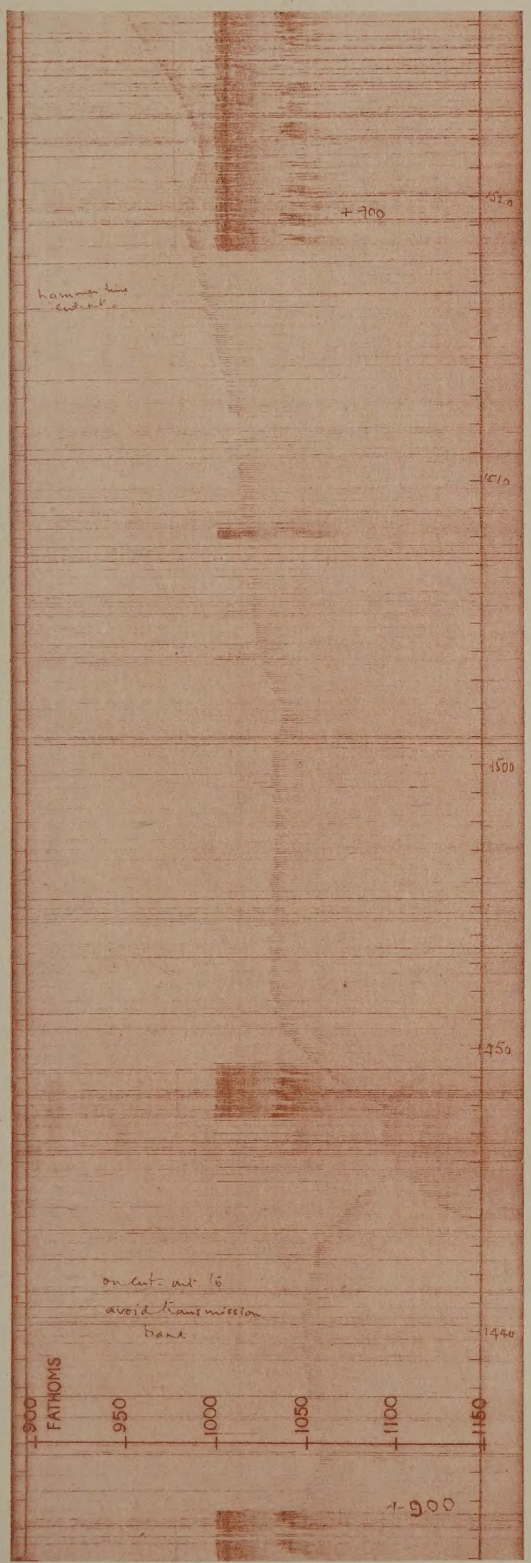
+700
1510
1500
1450
1440
FATHOMS
900
950
1000
1050
1100
1150
1-900

Fig. 1

0728
0731
FATHOMS
0
20
40
60
80
100
120
0858
PHASED

Fig. 2